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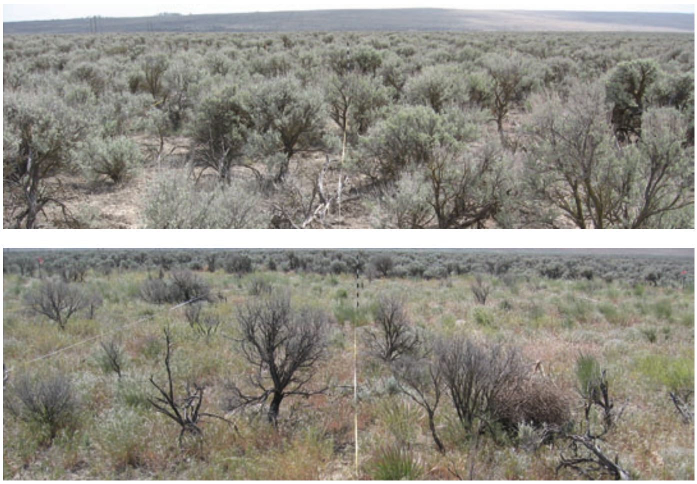
A Field Guide for Selecting the Most Appropriate Treatment in Sagebrush and Piñon-Juniper Ecosystems in the Great Basin

Evaluating Resilience to Disturbance and Resistance to Invasive Annual Grasses, and Predicting Vegetation Response

Richard F. Miller, Jeanne C. Chambers, and Mike Pellant

Warm and dry Wyoming big sagebrush—Invaded State



Cool and dry mountain big sagebrush—Reference State

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Abstract

This field guide identifies seven primary components that largely determine resilience to disturbance, as well as resistance to invasive grasses and plant succession following treatment of areas of concern. The primary components are (1) characteristics of the ecological site, (2) current vegetation prior to treatment, (3) disturbance history, (4) type, timing, and severity of the treatment, (5) post-treatment weather, (6) post-treatment management, especially grazing, and (7) monitoring and adaptive management. A series of key questions and a set of tools are provided to assess these primary components. This assessment is designed to allow field personnel to (1) evaluate resilience to disturbance and resistance to invasive annual grass for an area of concern, (2) predict the potential successional pathways, and (3) then select the most appropriate treatment, including the need for seeding. An evaluation score sheet is included for rating resilience to disturbance and resistance to invasive annual grasses and the probability of seeding success.

Keywords: restoration, resilience, resistance, succession, sagebrush, prescribed fire, mechanical treatment, piñon, juniper

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Introduction

One of the most challenging roles of a resource manager is conducting vegetation treatments across broad heterogeneous landscapes. In the Great Basin and Columbia River Plateau regions, a primary focus of vegetation treatments is on reducing woody species (shrubs and/or trees) to (1) reduce fuel loads and thus fire severity and extent, (2) increase perennial herbaceous species, which largely determine resilience to disturbance (recovery potential) and resistance to invasive annuals, (3) decrease the longer term risk of conversion to invasive annuals, and (4) maintain watershed integrity. Key elements of successful vegetation treatments designed to meet these objectives are the ability to evaluate an area's resilience to disturbance or treatment, such as tree removal and resistance to invasive annual grasses, and to predict potential post-treatment successional pathways. This requires identifying and understanding the primary components and ecological site characteristics that determine resilience to management treatments and resistance to invasive annuals and that drive plant successional pathways.

This field guide is designed to enhance the ability of managers to identify and evaluate these primary components and to effectively meet management objectives in sagebrush and piñon and/or juniper ecosystems when those objectives include increasing or restoring resilience to disturbances including wildfires and stressors like climate change, and resistance to invasive annual grasses for areas of concern. Resilient ecosystems have the capacity to *regain* their fundamental structure, processes, and functioning following disturbance, stressors, and management treatments. The resilience of an ecosystem is determined by its environmental characteristics and ecological conditions such as current vegetation, and reflects its recovery potential. Resistant ecosystems have the ability to *retain* their fundamental structure, processes, and functioning (or remain largely unchanged) despite disturbance and stressors. The resistance of an ecosystem to invasive annual grasses is a function of the environmental and ecological characteristics of an ecosystem that limits the population growth and expansion of the invasive species. Ecosystems that are both resilient and resistant provide valuable ecosystem services such as clean air, water, forage, and wildlife habitat.

Purpose

The field guide provides a framework for evaluating potential treatment areas within sagebrush and piñon pine and/or juniper ecosystems in the Great Basin and Columbia River Plateau that are being considered for vegetation management treatments. This framework helps managers evaluate the following characteristics of a potential treatment area:

1. Resilience or potential recovery following vegetation treatments such as prescribed fire and mechanical treatments;
2. Resistance to invasive annual grasses and the risk of increases in invasive annual grasses following vegetation treatments;
3. Likely plant successional pathways following vegetation treatments; and
4. The most appropriate vegetation treatments based on the relative resilience and resistance of the ecosystem and the likely successional pathways. Vegetation treatments addressed include prescribed fire and mechanical treatments to decrease fuel loads, increase native perennial grasses and forbs, and reduce the risk of invasive annual grass dominance. The need for post-fire rehabilitation treatments to stabilize soils and reestablish vegetation communities is also addressed.

Although this field guide is intended to assist in evaluating areas being considered for vegetation management treatments, the concepts, components, and questions are generally applicable to areas burned by wildfire or otherwise disturbed.

Approach

A set of **Key Questions** related to **Seven Primary Components** (shown in fig. 1) for the treatment area are used to evaluate resilience to disturbance or treatment, resistance to invasive annual grasses, and potential successional pathways, and to determine the most appropriate management treatment.

Area of Application

This field guide was developed for the northern Great Basin and Columbia River Plateau (fig. 2), which encompasses 11 Major Land Resource Areas (MLRAs) (table 1). MLRAs are geographically associated land resource units, usually encompassing several to many million acres. They are characterized by particular

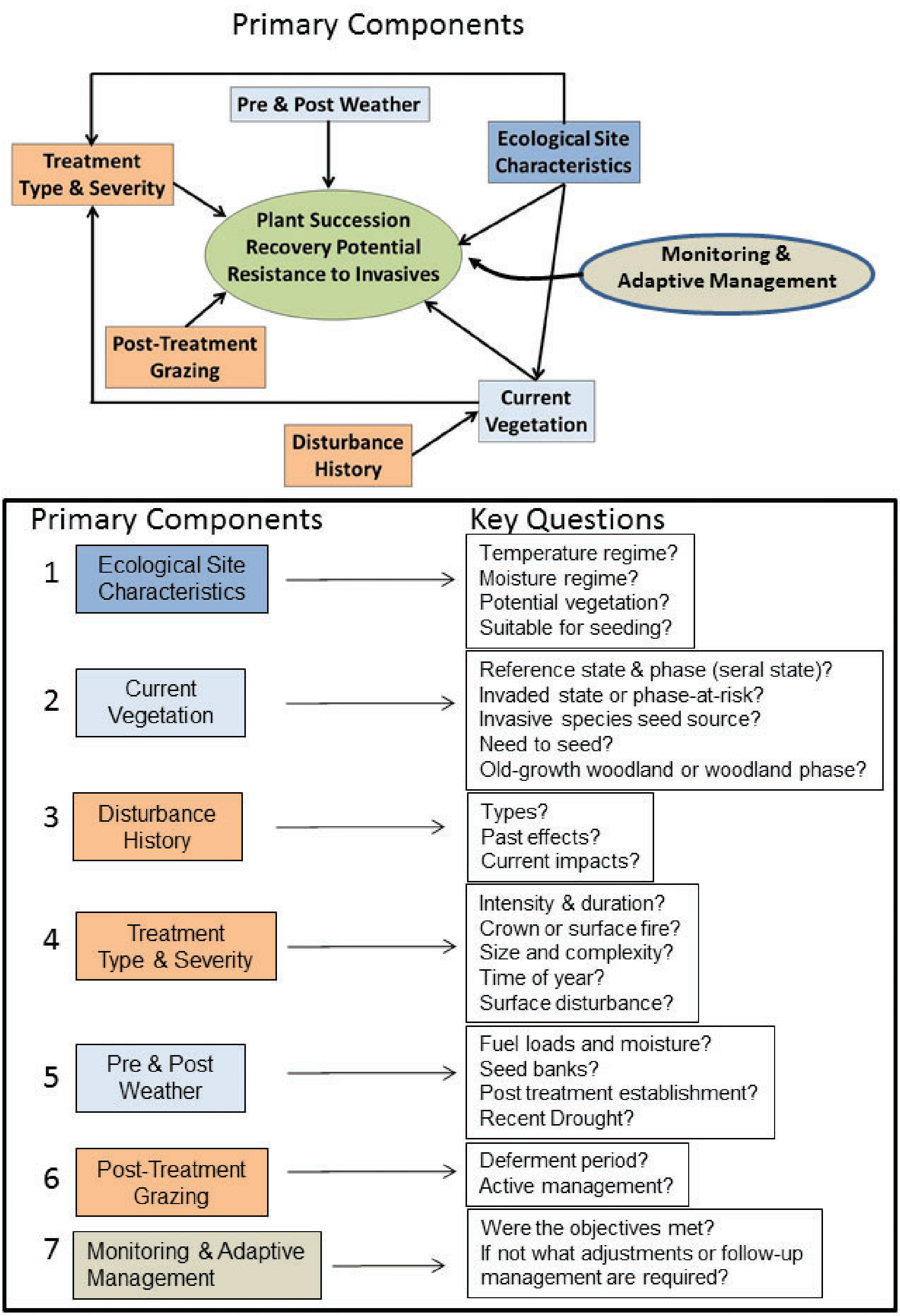


Figure 1. A conceptual model of the primary components that drive plant successional trajectories following prescribed fire or mechanical treatment. These components are the basis for a series of key questions to be addressed when evaluating site resilience to treatment applications and resistance to invasive annual grasses and predicting post-treatment responses.

patterns of soils, geology, climate, water resources, and land use. The MLRA in which the proposed treatment area is located provides important information for site evaluation and includes:

1. The elevation, topographic position, and indicator species that are used to identify **soil temperature/moisture regimes**, and that are closely linked to resilience to disturbance atnd management treatments and resistance to invasives (see fig. 3 and Appendix 1).
2. **The relevant ecological site descriptions** (ESDs, see Appendix 9 for definition). ESDs are usually unique to each MLRA, but similar ESDs may occur across MLRAs.
3. **The potential vegetation** (see Appendix 9)**.** Species composition may change across MRLAs, but the functional roles of plant groups (for example, deep-rooted and shallow-rooted perennial grasses, perennial forbs, and shrubs) are usually similar across MLRAs within the Great Basin and Columbia River Plateau regions.

When predicting vegetation response to vegetation treatments across different areas, comparing similarities among specific ecological **site characteristics** *(including soil moisture/temperature regimes and composition of the plant groups, such as deep-rooted perennial grasses) is usually more important than differences in geographic locations within or across MLRA's.*

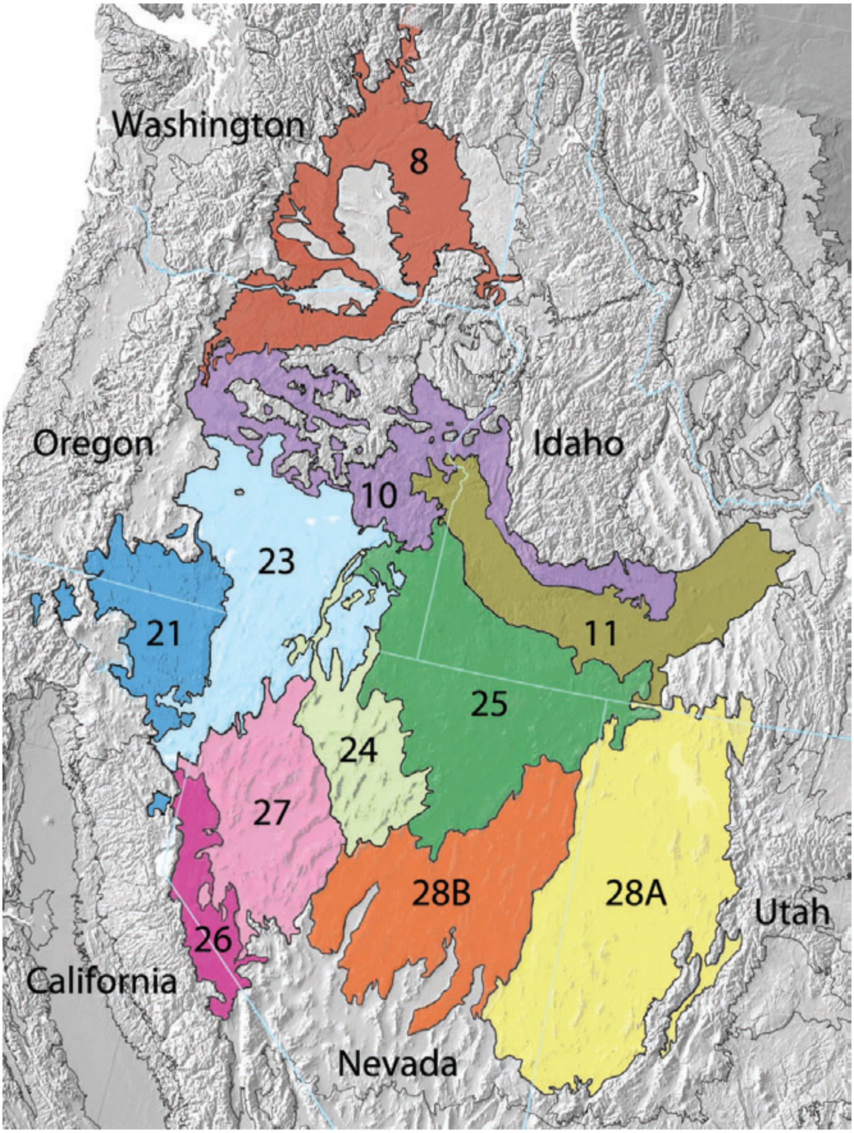


Figure 2. Major Land Resource Areas (MLRAs) located in the Great Basin and Columbia River Plateau Region: Columbia Plateau (8); Blue Mountain Foothills (10); Snake River Plain (11); Klamath Valleys (21); Malheur High Plateau (23); Humboldt Area (24); Owyhee High Plateau (25); Carson Basin and Mountains (26); Fallon-Lovelock (27); Great Salt Lake (28A); and Central Nevada Basin and Range (28B) (derived from USDA Natural Resources Conservation Service 2011 by Eugénie MontBlanc, University of Nevada, Reno, NV).

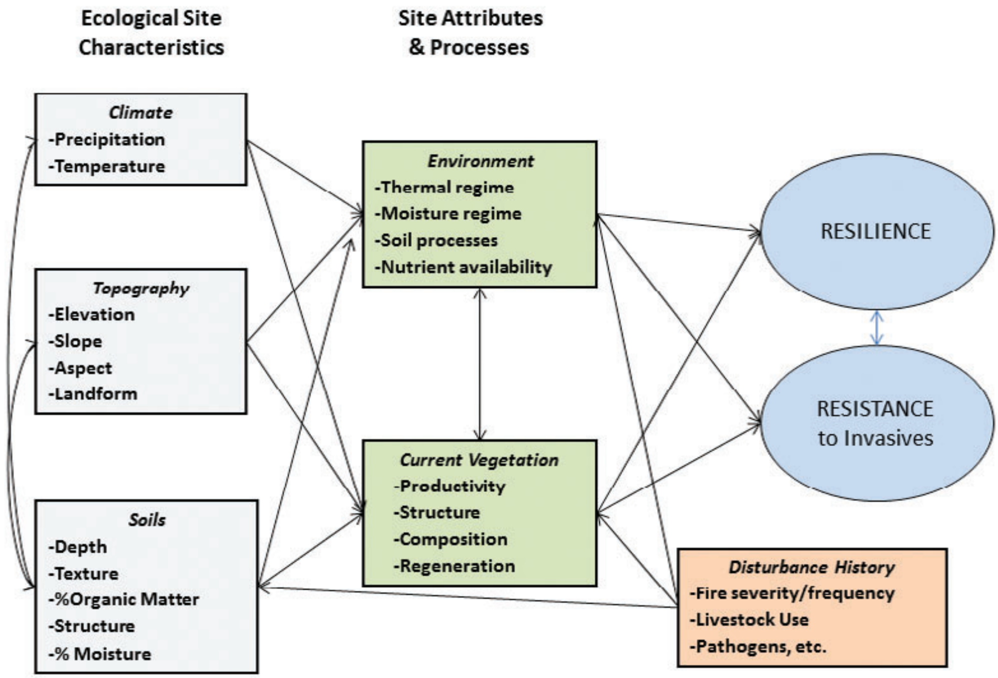


Figure 3. A conceptual model that illustrates the factors that influence resilience to treatment and resistance to invasive species. Ecological site characteristics or environmental factors are the primary factors that influence soil temperature/moisture regimes and potential vegetation. The regimes are identified in soil maps as mesic (warm), frigid (cool), cryic (cold), aridic (dry), and xeric (moist). Potential vegetation + disturbance history + time since disturbance or treatment = current vegetation. If all of the ecological site characteristics are favorable for treatment and the site attributes and processes are all functioning within the natural range of variability then levels of resilience to treatment application and resistance to invasive species are near potential for that site. However, if the site is not at potential because one or more components are below potential or missing, for example, perennial grasses are severely depleted or invasive annual grasses are abundant, resilience to disturbance and/or resistance to invasive annual grasses will be lower than potential (adapted from Chambers and others 2014).

Table 1. Major Land Resource Area (MLRA) names and identification numbers (see fig. 2 for map) included in this field guide. The size of land area, states listed in descending order of proportion of area it covers, most common elevation range (extreme), geology, common soil orders, range of average annual precipitation (extremes), and range in temperatures are described for each MLRA. The field guide covers only the sagebrush, salt-desert, and piñon pine and juniper communities within these MLRAs. MLRAs 8, 10, and 11 are located in the Northwestern Wheat and Range Region. The remaining MLRAs are located in the Western Range and Irrigated Region. Descriptions are derived from USDA Natural Resources Conservation Service 2011.

MLRA (id #)	Area (mi^2)	States	Elevation ft	Geology	Soils	PPT inches	Temp °F
Columbia Plateau (8)	18,505	WA OR ID	1,300-3,600	basalt	Mollisols	10-16 (6-36)	48-54
Blue Mt Foothills (10)	17,515	OR ID	1,300-6,600	basalt alluvium sedimentary	Mollisols, Aridisols	8-16 (41)	36-53
Snake River Plain (11)	16,475	ID OR	2,100-5,000	Idaho Batholith, basalts	Aridisols	7-12 (20)	41-55
Klamath Valleys (21)	11,495	CA OR	2,600-4,600 (>7,000)	basalt rhyolite andesite	Mollisols	12-30 (9; 30-58)	39-52
Malheur High Plateau (23)	22,896	OR NV CA	3,900-6,900 (>9,000)	basalt & andesite	Aridisols, Mollisols	6 – 12 (>50)	39-52
Humboldt Area (24)	12,680	NV OR	3950-5,900 (>8850)	alluvium (some andesite & basalt)	Entisols, Inceptisols, Mollisols	6-12 (40)	38-53
Owyhee High Plateau (25)	28,930	NV ID OR UT	3,000-7,550 (>9,800)	andesite basalt rhyolite	Aridisols, Mollisols	7-16 (>50)	35-53
Carson Basin & Mts (26)	6,520	NV CA	3,900-6,550 (13,100)	granitic andesite basalt	Aridisols, Mollisols	5-36	37-54
Fallon-Lovelock (27)	12,565	NV CA	3,300-5,900 (<7,800)	alluvium andesite basalt	Aridisols, Entisols	5-10 (19)	43-54
Central NV Basin & Range (28B)	23,555	NV	3,950-6,560 basin 6,560-11,150 mts	playa lakebed deposits,	Aridisols, Entisols, Mollisols	5-12 (49)	39-53
Great Salt Lake (28A)	36,775	UT NV ID	4,900-6,550 basin 6,550-11,900 mts	carbonate (north) andesite basalt	Aridisols, Entisols, Mollisols	4-12 (basins) 8-36 (mountains)	34-52

Supporting Information

The framework for the field guide is based on a recent synthesis of the state-of-our-knowledge titled, *A Review of Fire Effects on Vegetation and Soils in the Great Basin Region: Response and Ecological Site Characteristics*, RMRS-GTR-308, by Miller and others 2013. Additional information required for evaluating areas being considered for treatment includes soil surveys, ecological site descriptions, and potential and current vegetation (see http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm; http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/ecoscience/desc/).

This field guide is not a guide for restoration/rehabilitation strategies following vegetation treatments. However, the components and questions in the guide can be used to evaluate the suitability of an area for seeding based on ecological site characteristics and the need for seeding based on current vegetation. A companion field guide is being prepared that specifically addresses how to evaluate the resilience and resistance of an area immediately following a wildfire, the area's suitability for seeding, and the need for seeding after wildfire. It is titled *A Field Guide for Determining Post-Fire Recovery and the Need for Post-Fire Seeding in Sagebrush and Piñon-Juniper Ecosystems in the Great Basin*. Once the suitability of a site and need for seeding have been determined, restoration/rehabilitation methods can be found in references such as *Field Guide for Restoration of Sagebrush-Steppe: Ecosystems with Special Emphasis on Greater Sage-grouse Habitats*, by Pyke and others, in process, and *Restoring Western Ranges and Wildlands*, by Monsen and others 2004.

Basic Questions to Address Prior to Implementing Vegetation Treatments

1. What is the resilience (recovery potential) of the ecological sites across the proposed treatment area?
2. How resistant are the ecological sites to invasive annual grasses on the proposed treatment area?
3. How will different types of treatments and their severity influence resilience, resistance to invasives, and successional pathway(s) for the proposed treatment area?
4. Based on answers to the above three questions, what are the most appropriate vegetation treatment(s) for the proposed treatment area?

To address these questions specific characteristics of the seven primary components should be considered.

The Seven Primary Components

Ecological function and plant successional pathways are closely related to and dependent on (1) ecological site characteristics + (2) current vegetation (composition and structure) + (3) disturbance history + (4) treatment type, timing, severity, and frequency + (5) post-treatment weather + (6) post-treatment grazing + (7) monitoring and adaptive management

The key questions identify specific characteristics of the seven primary components that drive plant succession following treatment and influence longer-term outcomes (fig. 1).

Key Questions Addressing Each of the Seven Primary Components

1-Ecological Site Characteristics

Climate, topography, and soils affect water availability, temperature regimes, potential vegetation, and productivity, which in turn affect resilience to disturbance and treatments and resistance to invasives (fig. 3; Appendix 1). Due to underlying differences in characteristics of ecological sites, resilience to treatment and resistance to annual invasive species differs. Five generalized ecological types for big sagebrush in the Great Basin and Columbia River Plateau regions are presented in table 2. They represent groupings of ecological sites that are occupied by Wyoming or mountain big sagebrush, span a range of soil temperature/moisture regimes (warm-dry to cold-moist), and characterize a large portion of the Great Basin and Columbia River Plateau regions. To determine the relative resilience and resistance of specific or generalized ecological sites in the area prior to treatment, it is necessary to evaluate the soil temperature/moisture regimes, potential vegetation, and current vegetation.

In ecology, the term **mesic** is often used to mean moist or medium water supply for plant growth. However, in soil terminology and used in soil family names, mesic refers to warm soils, which in the Great Basin are often occupied by Wyoming big sagebrush and have relatively low resistance to invasive annual grasses (see Appendix 3).

Table 2. The five generalized ecological types for big sagebrush, their characteristics, and their resilience to wildfire and resistance to invasive annual grasses.

Ecological Type	Site Characteristics	Resilience and resistance
Warm and dry **Wyoming Big Sagebrush**	Soil temperature/moisture regime: Mesic/aridic Precipitation (Ppt): 8-12-in Indicator shrubs: *Artemisia tridentata* ssp. *wyomingensis* Indicator grasses: *Pseudoroegneria spicata, Achnatherum thurberianum* on cooler/moister sites; *A. hymenoides, A. comata, Elymus elymoides, Poa secunda* on drier/warmer sites	***Resilience –*** Low. Effective precipitation limits site productivity. Decreases in site productivity, herbaceous perennial species, and ecological conditions further decrease resilience. ***Resistance –*** Low. High climate suitability to cheatgrass and other invasive annual grasses. Resistance generally decreases as soil temperature increases, but establishment and growth are highly dependent on precipitation and vary among years.
Warm and moist **Big sagebrush** **Piñon and Juniper Potential**	Soil temperature/moisture regime: Cool mesic to warm frigid/xeric Ppt:12-14-in Indicator shrubs: *A. tridentata* ssp. *wyomingensis, A. tridentata* ssp. *vaseyana, Purshia tridentata* Indicator grasses: *Pseudoroegneria spicata*	***Resilience –*** Moderate. Precipitation and productivity are moderately high. Decreases in site productivity, herbaceous perennial species, and ecological conditions can decrease resilience. ***Resistance –*** Moderately low. Climate suitability to invasive annual grasses is moderately low, but increases as soil temperatures increase.
Cool and moist **Mountain big sagebrush**	Soil temperature/moisture regime: Cool mesic to cool frigid/xeric Ppt: 12-14-in Indicator shrubs: *Artemisia tridentata* ssp. *vaseyana, Purshia tridentata* Indicator grasses: *Festuca idahoensis, Poa fendleriana*	***Resilience –*** Moderate. Precipitation and productivity are moderately high. Decreases in site productivity, herbaceous perennial species, and ecological conditions can decrease resilience. ***Resistance –*** Moderate. Climate suitability to invasive annual grasses is moderate, but increases as soil temperatures increase.
Cool/cold and moist **Mountain big sagebrush** **Piñon and Juniper Potential**	Soil temperature/moisture regime: Cool frigid/xeric Ppt: 12-14-in + Indicator shrubs: *A. tridentata* ssp. *vaseyana, Amelanchier* ssp., *Symphoricarpos* ssp. Indicator grasses: *Festuca idahoensis, Koeleria macrantha, Melica bulbosa*	***Resilience –*** Moderately high. Precipitation and productivity are generally high. Decreases in site productivity, herbaceous perennial species, and ecological conditions can decrease resilience. ***Resistance –*** Moderately high. Low climate suitability to invasive annual grasses.
Cold and moist **Mountain big sagebrush**	Soil temperature/moisture regime: Cryic/xeric Ppt: 14-in + Indicator shrubs: *A. tridentata* ssp. *vaseyana, Amelanchier* ssp., *Symphoricarpos* ssp. Indicator grasses: *Festuca idahoensis, Koeleria macrantha, Melica bulbosa*	***Resilience –*** Moderately high. Precipitation and productivity are generally high. Short growing seasons can decrease resilience on coldest sites. ***Resistance –*** High. Low climate suitability to invasive annual grasses.

Soil Temperature Regime

1. Are the soils warm (mesic), cool (frigid), or cold (cryic) (fig. 4 A and B)?
   a. This information can be attained from soil maps, soil family names, and/or elevation based on criteria used for soils mapping in the appropriate MLRA (Appendices 2 and 3). Plant species composition also can be an indicator (see Potential Vegetation below).
2. Do elevation and aspect place the ecological site on the upper or lower end of the soil temperature regime (for example, warm-mesic versus cool-mesic) (fig. 4)?

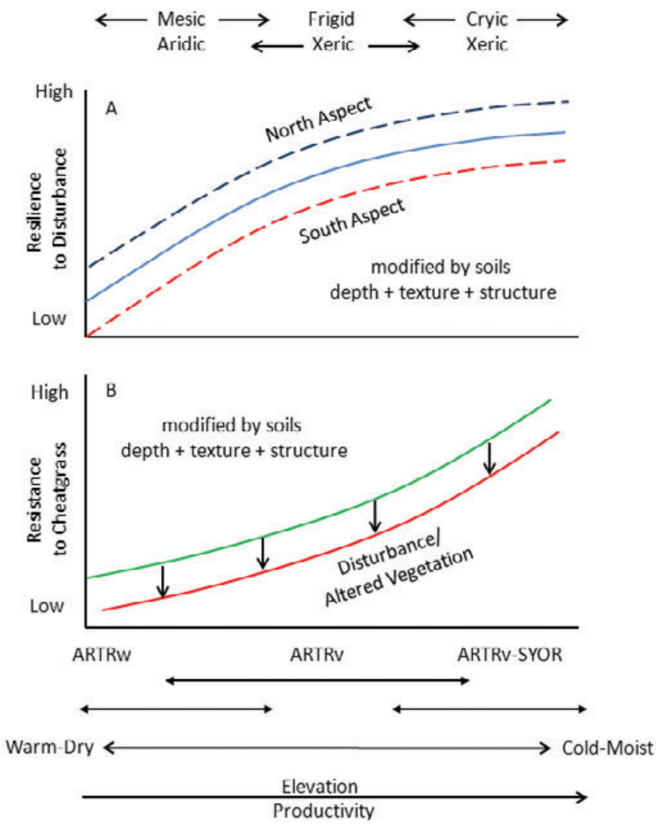


Figure 4. A conceptual model of (A) resilience to treatment and (B) resistance to invasive annual grasses for Wyoming big sage (ARTRw), mountain big sagebrush (ARTRv), and mountain big sagebrush-snowberry (ARTRv-SYOR) along an elevation/productivity gradient in which soil temperature/moisture regimes grade from warm-dry (mesic-aridic) to cold-moist (cryic-xeric). Soil moisture availability along these gradients is modified by soil characteristics. The mountain big sagebrush-snowberry (ARTRv-SYOR) type is similar to mountain shrub in Nevada and Utah and often includes mountain big sagebrush, snowberry, serviceberry, bitterbrush, and curl-leaf mountain mahogany. Resilience and resistance are affected by topography; the dashed dark blue and red lines in the resilience graph illustrate the effects of aspect. The potential resilience and resistance of a site is determined by ecological site characteristics; resilience and resistance can be lowered if certain site components such as perennial grass abundance are depleted as a result of disturbance history or climate change. In the resistance graph, the solid green line represents potential resistance to annual invasives in the reference state and the red line indicates decline in resistance as a result of a phase being at-risk. The relationship between soil temperature/moisture regimes and elevation changes across MLRAs (see Appendix 2). Soil temperature/moisture regimes are not separated by distinct boundaries but represent a gradient (shown by the overlapping arrows). Changes in soil temperature and moisture can be gradual (a gradual increase in elevation) or abrupt (a shift from a south to an opposing north aspect). The shift from one sagebrush subspecies to another does not have a definite lower or upper elevation limit, but will vary with other site attributes including location (MLRA), soils, aspect, and microtopography. For example, an overlap of cool (frigid) mountain big sage (ARTRv) into warm (mesic) Wyoming big sagebrush (ARTRw) can occur, and is often influenced by soil moisture availability. As environmental gradients move to the right, resilience and resistance increase. Productivity and thus fuel loads also increase resulting in a greater potential for more frequent fires. (from Chambers and others, 2013).

In reality soil moisture/temperature regimes are gradients. Thus, it helps to know if the ecological site is warm, mid, or cool relative to a specific soil temperature regime (fig. 4, Appendix 2). This usually can be determined by the elevation and aspect of the ecological site. Indicator plant species also can be helpful. North and south aspects with >15% slope are usually adjusted by 500 ft. For example, in MLRA23 the elevation boundary for mesic and frigid soils is 4000 ft, but it is adjusted down to 3500 ft on north aspects and up to 4500 ft on south aspects.

Soil Moisture Regime

3. Does the ecological site have a dry aridic (<10-in ppt), aridic (10-12-in ppt), or xeric (>12-in ppt) moisture regime? (See table 3 and figs. 5 and 6 for indicator species.)
4. Is the soil depth very shallow (<10-in), shallow (10-20-in), moderately deep (20-36-in), or deep (>36-in)?
    a. Soil depth influences the water storage capacity of the ecological site. Some very shallow soils (<10-in) may be mapped as aridic due to limited water storage capacity even though annual precipitation is >12-in (xeric).
    b. A general estimate of soil depth can be determined by the species or subspecies of sagebrush and their height (fig. 5 and table 3). However, digging small soil pits is the best technique to determine soil depth in a proposed treatment area.
5. Is the soil texture clay, sandy, silt, loam, clay-loam, sandy-loam, silt-loam (see Appendix 3)?
    a. Texture is an important soil characteristic because it influences soil water capture and storage. Soils with loamy textures have the greatest capacity for both capturing and storing water for plant use.

Table 3. Site characteristics that often occur with different sagebrush and associated shrub species. Lower elevation limits vary widely across Major Land Resource Areas. For example, the elevation where the transition of Wyoming to mountain big sagebrush occurs (modified by aspect) is commonly around 4500 ft in the High Malheur Plateau (MLRA 23) and 6500-7500 ft in the Central Nevada Basin and Range (MLRA 28B) (from USDA-NRCS Plant Guide; Mahalovich and McArthur 2004). Precipitation (PPT) values in parentheses indicate extremes.

Species	PPT (in)	Elevation (ft)	Soil			
			Depth (in)	Moisture regime	Temperature regime	Soil properties
Wyoming big sagebrush	8-12(6)	2600-7200	10-30	Aridic	Mesic	Loamy soils with high clay content
Basin big sagebrush	8-16	600-2100	>36	Aridic-xeric	Mesic	Loamy to sandy
Mountain big sagebrush	>12	2600-10000	18-36	Xeric	Frigid-cryic	Loamy to gravely to clay loam
Xeric big sagebrush	12-16	2600-4900 (7200)	>16	Xeric	Mesic (frigid)	Basalt or granitic
Low sagebrush		2300-12000	<20	Aridic-xeric	Frigid-cryic (mesic)	Rocky, shallow, clay soils
Black sagebrush	<12	2000-10000	<20	Aridic xeric	Mesic-frigid	Shallow, stony, calcareous
Snowbank big sagebrush	>12	6800-10000	>20	Xeric	Cryic	Snow accumulation areas
Other Shrubs						
Snowberry	>14	4800-10000	>20	Xeric	Cool frigid to cryic	Sandy to clay loams
Serviceberry	>14	5000-8500	>20	Xeric	Cool frigid-cryic	Loam
Shadscale	4-8	4000-7000	>20	Dry-aridic	Mesic-frigid	Aridisols (uplands)
Spiny hopsage	<8	2000-5500	>20	Dry-aridic	Mesic	Aridisols
Mormon tea	<10 (15)	3000-7500	>20	Dry-aridic	Mesic	Sandy, gravely, rocky aridisols

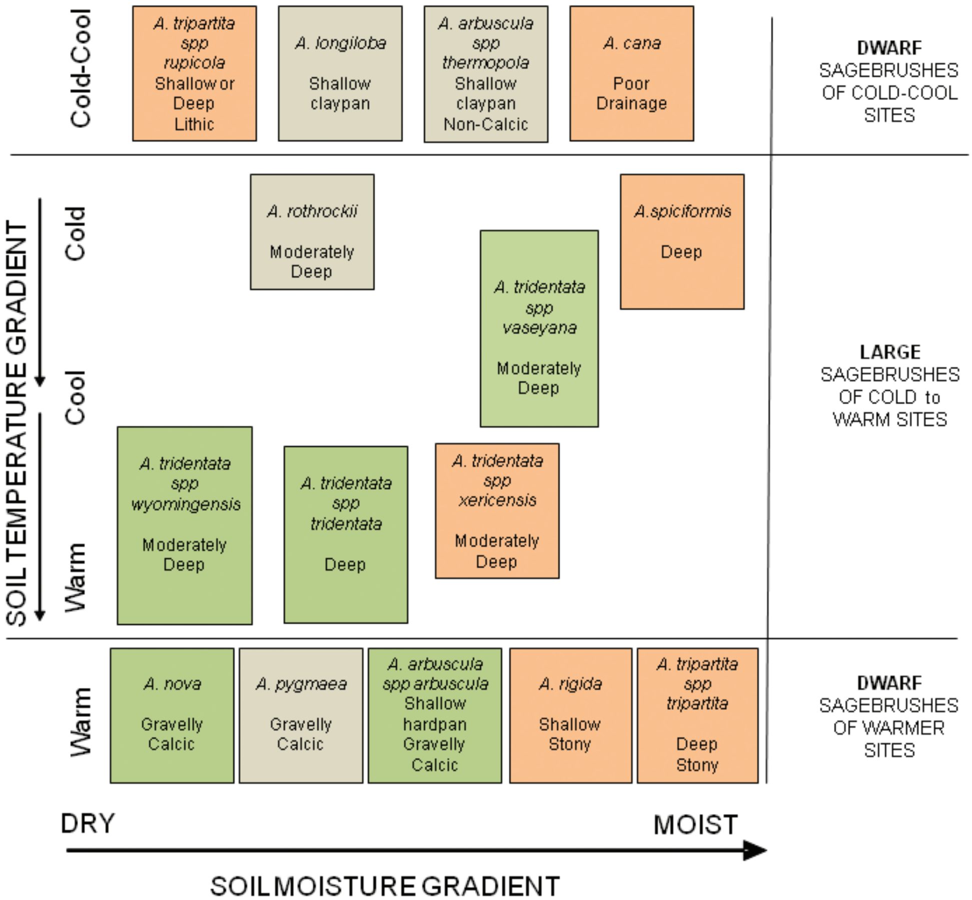


Figure 5. Major sagebrush taxa in the Great Basin and Columbia River Plateau positioned along gradients of soil temperature and soil moisture (adapted from Robertson and others 1966; McArthur 1983; West 1983; West and Young 2000; Rosentreter 2005; Schultz 2009, 2013). Key soil characteristics associated with each species are shown under the species name. Relative abundance of the sagebrush species and subspecies in the Great Basin and Columbia River Plateau is color coded: tan = scarce, orange = common, and green = dominant.

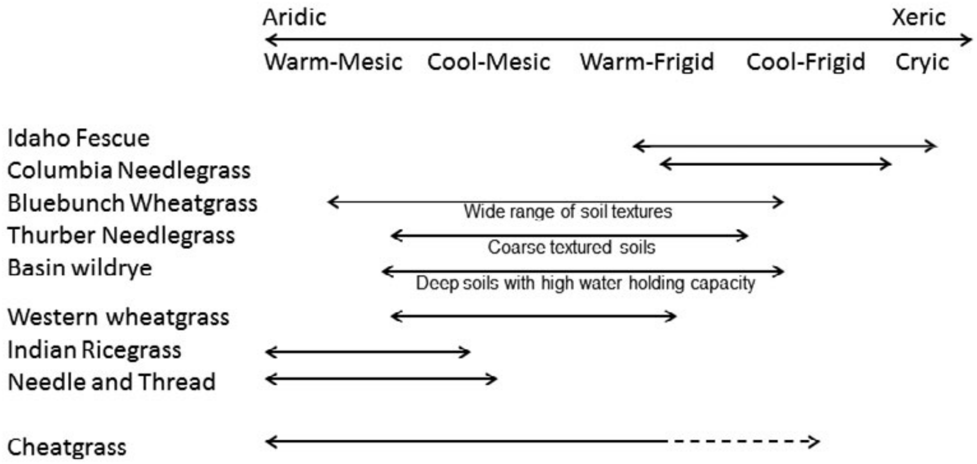


Figure 6. The general distribution of common, deep-rooted grasses and cheatgrass across a soil moisture/temperature gradient in the Great Basin and Columbia River Plateau.

What is in a soil family name?

A soil family name includes important information on related soil characteristics that influence ecological site resilience to treatment, resistance to invasives, and potential vegetation. This includes information related to relative organic matter content (Aridisols or Mollisols), soil depth (for example, mention of a restrictive layer), texture, and the soil temperature/moisture regime (mesic, frigid, or cryic, and aridic or xeric) (see Appendix 3 for examples).

Potential Vegetation

The potential vegetation of an ecological site, as described in an ESD, is a function of ecological site characteristics (climate, topography, and soils), attributes and processes (soil temperature/moisture regime, soil processes, and vegetation dynamics), and disturbance regime (fig. 3). Due to strong topographic gradients, which influence moisture and temperature and thus potential vegetation in the Great Basin and Columbia River Plateau, dominant plant species such as sagebrush are good indicators of soil temperature/moisture regimes (table 3).

1. What is (are) the dominant shrub species or subspecies of sagebrush (fig. 5, table 3; see Shultz 2013)?
   a. Wyoming big sagebrush is most commonly found on moderately deep, mesic/dry-aridic to aridic (warm/dry) soils but can occur on warm-frigid soils, especially if the moisture regime is aridic (fig. 4).
   b. Mountain big sagebrush is most commonly found on moderately deep frigid/xeric soils but also occurs on warm-cryic soils.

2. Some shrub species associated with sagebrush (usually present or co-dominant but not dominant) are also indictors of soil temperature/moisture regimes. For example, snowberry and serviceberry are common on cool-frigid and cryic soils with ≥14-in precipitation. In upland non-saline soils, shadscale and spiny hopsage often occur on mesic/dry-aridic soils typically with <8-in precipitation (table 3).
3. What are the perennial grass species that potentially dominate a site?
   a. The perennial grass species that are potentially common or dominant in the reference state (see Appendix 9 for definition) for the ecological site are general indicators of moisture availability, temperature (fig. 6), and soil depth and texture.
   b. If Sandberg's bluegrass is the dominant grass it can be an indicator of very shallow soils (<10-in) or if on shallow to moderately deep soils (>10-in) of inappropriate grazing resulting in the loss of larger bunchgrasses. Also, a high abundance of bottlebrush squirreltail is often an indicator of high severity and/or frequent disturbance. However, these two species increase resilience and resistance to invasive annual grasses where soils are shallow, on relatively warm and dry sites, and where perennial, native herbaceous species have been depleted.
4. Is the reference state a shrubland or piñon pine and/or juniper woodland?
   a. Are there old-growth juniper and/or piñon pine on the proposed treatment area?
   b. Are there remnants of large tree stumps or logs, which show evidence of fire that indicate the area was previously occupied by large trees?

Note that some ecological site descriptions that include piñon pine or juniper in the reference state do not differentiate old growth and post-settlement trees. However, in newer ESDs with state and transition models, it is easier to make this distinction. To determine the type of woodland, see the "Piñon Pine and/or Juniper Encroachment" section below.

2-Current Vegetation

Current vegetation plays a major role in the recovery of an ecological site following treatment. The persistence and abundance of perennial vegetation immediately following treatment is one of the primary drivers of both short- and long-term successional pathways. Post-treatment persistence and abundance of perennial vegetation are a function of pre-treatment plant community composition and structure, treatment type, timing, and severity, and species' tolerance to the treatment.

Perennial Grasses and Forbs

1. What is the composition and structure (cover and/or density) of perennial native grasses and forbs?
   a. Are they scarce to absent?
   b. Are they severely depleted? *(perennial grasses are <2/10ft^2 for xeric and <3/10ft^2 for aridic; invasives dominant or, if invasives are not dominant, woody species [shrubs or trees] are near maximum cover)*
   c. Depleted or codominant with invasive annual grasses? (*Abundance of perennial grasses and forbs are near or equal to abundance of invasives [annual exotic abundance is highly variable with moisture]. If invasives have low abundance [<5% cover], perennial grass densities >2/10ft^2 for xeric and >3/10ft^2 for aridic but cover typically does not exceed 10%.)*
   d. Dominant (near reference state).

Invasive Annual Grass Potential

1. What is the potential for invasive annual grasses and other invaders to increase based on ecological site characteristics (figs. 3 and 4), seed source (on or off site), and the type, timing, and severity of treatment?
   a. Do the perennial native herbaceous species have sufficient density and/or cover to ensure ecological site recovery? The density and/or cover of native perennial herbaceous species necessary for post-treatment recovery will vary with ecological site characteristics, severity and timing of the treatment, and post-treatment weather (fig. 1).
   b. Resistance to invasive annual grasses and other annual invasives decreases as a function of ecological site characteristics that include warmer soil temperatures and drier moisture regimes (fig. 4B, table 2). As resistance decreases, the abundance of residual vegetation required for recovery increases. Data are limited, but one example showed that following the removal of a closed western juniper stand on the low elevation end of a cool soil temperature regime (warm-frigid) (southwest slope at 5000 ft in the Malheur High Plateau MLRA), 2-3 deep-rooted perennial grasses per 10 ft^2 was sufficient for bunchgrasses to recover (Bates and others 2007). A second example showed that following either prescribed fire or mowing of sagebrush on Wyoming big sagebrush sites with mesic soil temperature regimes in six MLRAs (Columbia Basin, Columbia Plateau, Malheur High Plateau, Snake River Plains and Great Salt Lake Area), a 20% cover of perennial native herbaceous species (both grasses and forbs) was required to prevent significant increases in cheatgrass after treatment (Chambers and others, in press). These examples indicate that higher cover or densities of perennial herbaceous

species may be required for post-treatment recovery on warmer and drier sites with lower resistance to annual invasive species.

c. What are the current composition, distribution, and abundance of invasive annual grasses and other invaders? Note that the densities, cover, and biomass of annual species are highly variable among years, and values obtained in a dry spring often will not reflect those obtained in an average or wet spring.

On a mesic/aridic ecological site, annual grass cover in one long-term study varied from trace in dry years to 25% in wet years.

d. What is the potential for invasive annual grasses and other invaders to increase on the treatment site based on seed source (on or off site), current disturbances, and future livestock grazing?

Piñon Pine and/or Juniper Encroachment?

1. If piñon pine and/or juniper are present on the proposed treatment area, what type of woodland is it?

   a. Is the area comprised largely of: (a) old growth (>10% canopy cover); (b) a low density of old trees scattered across the area (<10% cover) and infilled with post-settlement trees; or (c) post-settlement trees where old growth is either absent (including old stumps and logs) or isolated to specific topographic positions (for example, ridges) and/or soils? To distinguish historic woodlands from encroachment areas the following questions can be addressed:

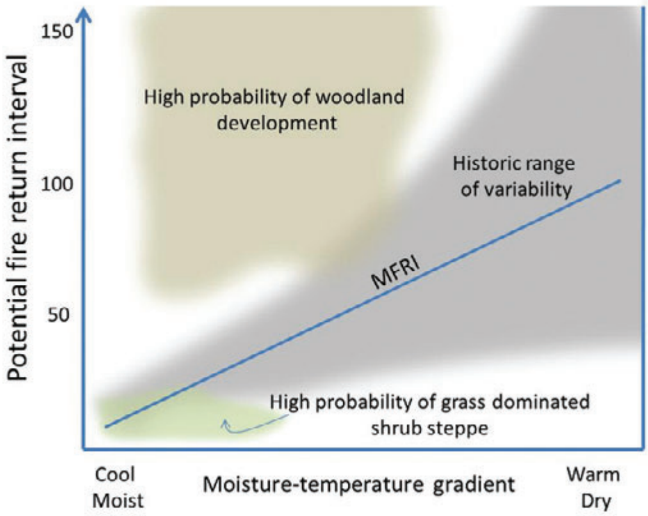
      i. What is the age structure of live trees (based on morphology, see Appendix 4a, b)?

      ii. Are there large stumps, burned snags, or logs indicating mortality of large trees from a past fire? If yes, would the projected tree cover (based on density of stumps, snags, and logs) have been open savanna-like (<10%) or woodland (>10%)?

      iii. What is the distribution of the old trees across the treatment area? Do they occur in small patches on specific kinds of soils or landscape positions, or do they occur across the majority of the area?

      Note that fire-return intervals of less than 40-50 years, especially on cooler, moister ecological sites, are usually required to limit the transition from shrubland to woodland where there is a piñon pine and/or juniper seed source nearby (fig. 7).

Figure 7. A conceptual model illustrating the range of potential historic mean fire-return intervals (MFRI, years between fires) in the Great Basin and Columbia River Plateau. MFRI increases along a moisture and temperature gradient from cool-moist to warm-dry as a result of decreasing fuel abundance and continuity. The combination of temperature, water availability for plant growth, and fire regime influences the potential natural vegetation that can persist as illustrated in figure 7. Sagebrush ecosystems gray; historic woodland is brow, and grassland is green. Persistent vegetation that occupies the gray area is likely a sagebrush herbaceous mix with relative abundance of each dependent on time since fire and ecological site characteristics (from Miller and others 2011). Packrat-midden and pollen data indicate that the proportion of each plant community type across the Great Basin has been dynamic during the Holocene (last 10,500 years) as a result of shifting climate and fire regimes.



b. If the treatment area is predominately old growth or contains patches of old growth, how does this influence management goals and treatment application?

c. If the trees are predominately young (<150 yrs) and have encroached or infilled into a location of concern that historically was predominately a shrubland community, the following questions should be addressed:

   i. Based on the density, canopy cover, and age structure, what is the woodland phase (see Appendix 9 for definitions)?

   ii. How will the density and size of trees influence fire behavior and severity (see fire severity below)?

   iii. How will fuel structure influence treatment selection and the ability to apply fire?

   iv. To what degree is the tree canopy influencing the understory composition and thus recovery potential?

   v. Is the grass and forb cover in the large interspaces between the trees severely depleted (<5% foliar cover) or moderately depleted (5-10% foliar cover)?

   vi. Is there high shrub mortality based on standing shrub skeletons or persistent litter?

   vii. Are there obvious signs of rill and sheet erosion that exceed the levels expected on the site (as described in the reference sheet for the appropriate ESD) (fig. 8)?

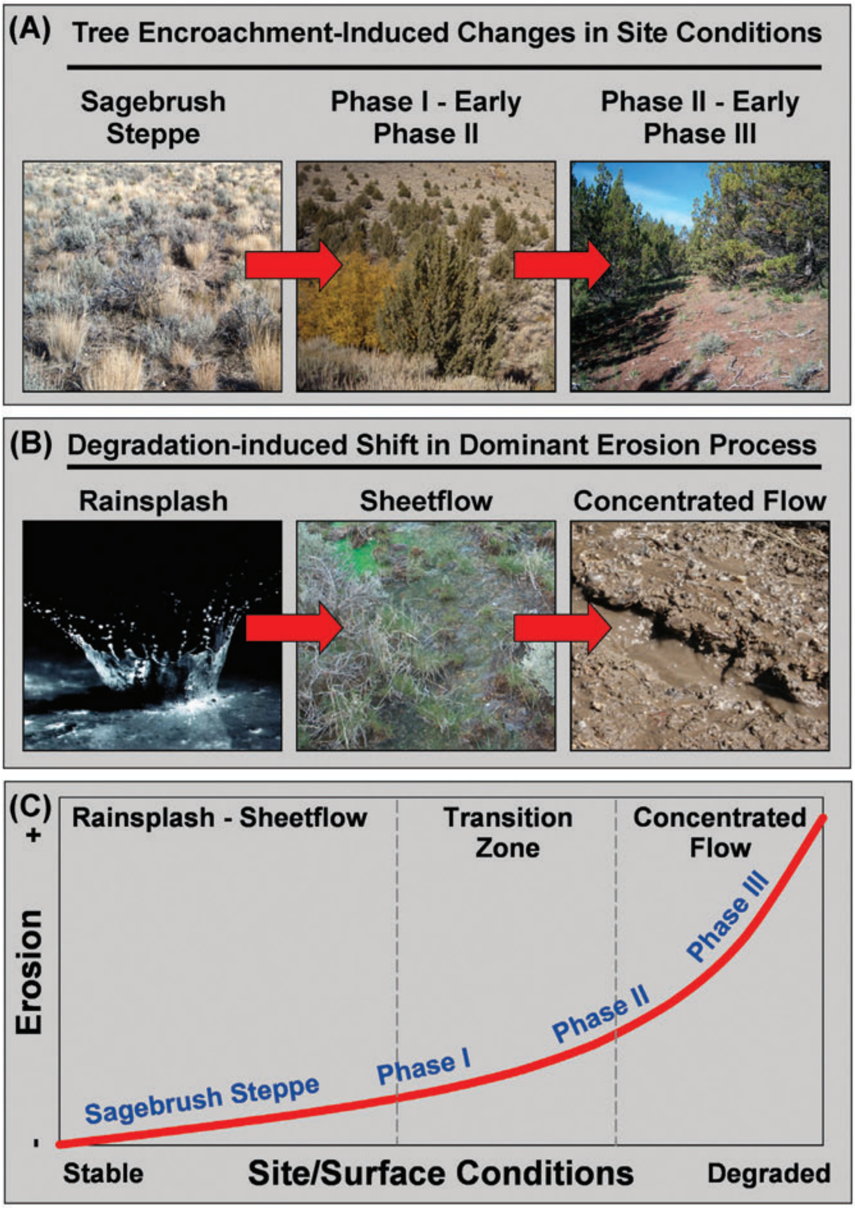


Figure 8. (A) Changes in sagebrush shrublands with advancing woodland encroachment; (B) the associated degradation-induced shift in the dominate erosion processes; and (C) a representative increase in erosion magnitude associated with changes in site/ground surface conditions. Erosion from stable sagebrush communities occurs primarily by rainsplash and sheetflow and is typically low. Erosion increases exponentially with site and ground surface degradation where bare soil increases beyond 50-60%. High rates of erosion typically occur where sagebrush communities transition to Phase II-III woodlands. The exponential increase in soil loss (C, red line) with site/ground surface degradation illustrates the effect of concentrated flow. Concentrated flow is the dominant erosion process at the transition from Phase II-III woodland encroachment and signals a transition from a stable to a degrading landscape. Concentrated flow has higher velocity than sheetflow and thereby exhibits greater sediment detachment and transport capacity than the combined effects of rainsplash and sheetflow (from Miller and others 2013).

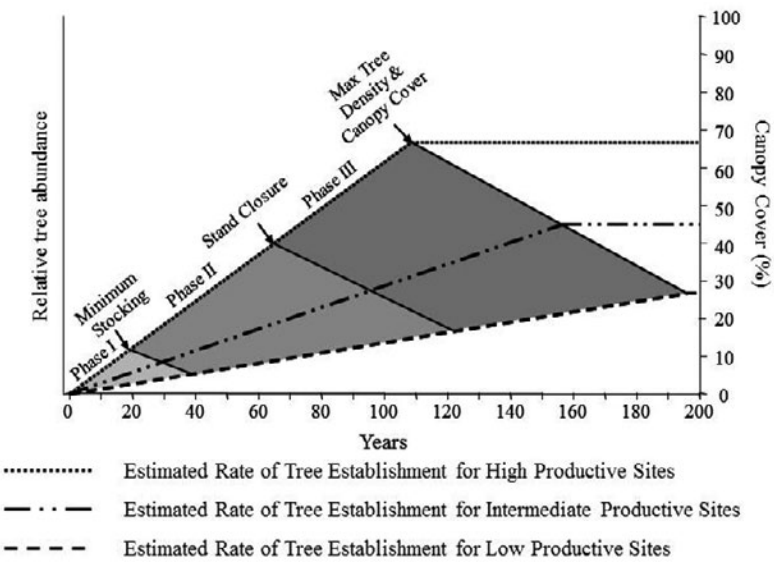


Figure 9. The hypothesized amount of time required from initial western juniper establishment (early Phase I) to a minimum stocking level adequate for Phase III, and the estimated maximum potential for tree density and cover for stands developing on varying elevations and aspects (from Johnson and Miller 2006). Projected rates of closure are similar for piñon pine and Utah juniper (Tausch and others 2009).

viii. If the woodland is in phase I or II (see Appendix 9 for definition), what is the expected rate of stand closure based on ecological site productivity (fig. 9)?

ix. What is the distance to the nearest piñon pine or juniper seed source? And, if the treatment area is large, what areas are most vulnerable to seed dispersal?

The majority of bird and small mammal disseminated juniper seed is dispersed within 300 ft of the seed source. However, birds can disseminate seed up to 3 miles or more.

2. What is the fire tolerance of plant species on the site?
   a. How fire-tolerant are native and invasive species on the ecological site and how will this potentially influence post-treatment composition?
   b. What is the fire tolerance of species of concern (for example, sagebrush or threatened and endangered species) and what is their potential for recovery after treatment implementation?
      i. Is the area sage-grouse nesting, brood rearing, or winter habitat?
      ii. What is the plant composition and structure of areas adjacent to the treatment area and how large is the treatment area?

Fire tolerance of most herbaceous vegetation often can be determined from visible morphological traits (table 4). When applying prescribed fire, it is important to distinguish shrubs that are sprouters and non-sprouters (table 5).

Table 4. Examples of some common perennial forbs in the Great Basin and Columbia River Plateau Regions and their tolerance to fire as related to their growth form.

Tolerant (damage none to slight)	Intolerant (damage—moderate to severe)
Buds below ground	**Buds above ground**
common yarrow (*Achillea millefolium*)	pussytoes (*Antennaria* spp.)
mountain dandelion (*Agoseris* spp.)	sandwort (*Arenaria* spp.)
onion (*Allium* sp.)	matted buckwheat. (*Eriogonum caespitosum*)
aster sp. (*Aster* sp.)	Douglas buckwheat (*Eriogonum douglasii*)
milkvetch sp. (*Astragalus* sp.)	parsnip buckwheat (*Eriogonum heracleoides*)
arrowleaf balsamroot (*Balsamorhiza* spp.)	slender buckwheat (*Eriogonum microthecum*)
mariposa lilly (*Calochortus* spp.)	rock buckwheat (*Eriogonum sphaerocephalum*)
hawksbeard (*Crepis* spp.)	sulfur-flower buckwheat (*Eriogonum umbellatum*)
fleabane (*Erigeron* spp.)	spiny phlox (*Phlox hoodii*)
sticky purple geranium (*Geranium viscosissimum*)	
old man's whiskers (*Geum triflorum*)	
biscuitroot (*Lomatium* spp.)	
lupine sp. (*Lupinus* spp.)	
bluebells sp. (*Mertensia* spp.)	
woolly groundsel (*Pakera cana*)	
penstemon spp. (*Penstemon* spp.)	
longleaf phlox (*Phlox longifolia*)	
lambstongue ragwort (*Senecio integerrimus*)	
largehead clover (*Trifolium macrocarpum*)	
death camus spp. (*Zigadenus* spp.)	
mules ear (*Wyethia amplexicaulis*)	

Derived from Blaisdell 1953; Pechanec and others 1954; Mueggler and Blaisdell 1958; Lyon and Stickney 1976; Klebenow and Beall 1977; Wright and others 1979; Volland and Dell 1981; Bradley and others 1992; Pyle and Crawford 1996; Riegel and others 2006; USDA-Forest Service 2013.

3-Disturbance History

1. How much has disturbance history altered the proposed treatment area?
2. What types of past disturbances have potentially impacted vegetation structure and composition?
3. How are current disturbances or management affecting existing vegetation structure and composition?

4-Treatment Type and Severity

As resiliency to disturbance(s) and resistance to invasive annual grasses and other invasives decreases, treatment severity becomes of greater concern and selection of the appropriate treatment method and timing becomes increasingly important (see the section below on "Selecting the Most Appropriate Treatment Method").

Table 5. Potential response of common shrubs to fire in the Great Basin and Columbia River Plateau Regions (s).

Tolerant	Moderately Tolerant	Intolerant
	Sagebrush Steppe	
silver sagebrush (*Artemisia cana*)(s) snowfield sagebrush (*Artemisia spiciformis*) (s) aspen (*Populus tremuloides*)(s) green rabbitbrush (*Chrysothamnus viscidiflorus*)(s) wax current (*Ribes cereum*)(s) desert gooseberry (*Ribes velutinum*)(s) Woods' rose (*Rosa woodsii*)(s) mountain snowberry (*Symphoricarpos oreophilus*)(s) horsebrush sp (*Tetradymia* sp.)(s) serviceberry (*Amelanchier alnifolia*)(s) Stansbury cliffrose (*Purshia stansburiana*)(s) desert bitterbrush (*Purshia tridentata* var. *glandulosa*)(s) Nevada Mormon tea (*Ephedera nevadensis*)(s)	rubber rabbitbrush (*Ericameria nauseosus*)(s) three-tip sagebrush (*Artemisia tripartita*)(ws)	low sagebrush (*Artemisia cana*)(ns) black sagebrush (*Artemisia nova*)(ns) big sagebrush (*Artemisia tridentata*)(ns) curl-leaf mountain mahogany (*Cercocarpus ledifolius*)(ws) antelope bitterbrush (*Purshia tridentata* var. *tridentata*)(ws) Mexican cliffrose (*Purshia mexicana*)(ws) broom snakeweed (*Guiterrezia sarothrae*)(ws)
	Desert Shrub	
greasewood (*Sarcobatus velutinus*)(s) Torrey's saltbush (*Atriplex torreyii*)(s) Gardner's saltbush (*Atriplex gardnerii*)(s)		spiny hopsage (*Grayia spinosa*)(ws) bud sagebrush (*Picrothamnus desertorum*)(ns) shadscale (*Atriplex confertifolia*)(ns) fourwing saltbush (*Atriplex canescens*)(ws) winterfat (*Krascheninnikovia lanata*)(ws)

S = sprouter; ws = weak sprouter; ns = non-sprouter. Derived from Blaisdell 1953; Mueggler and Blaisdell 1958; Nord 1965; Wright 1972; Wright and others 1979; West 1994.

Prescribed Fire

Pre-fire fuels assessment

1. How will the abundance and structure of current vegetation influence fire severity (see fig. 10)?
    a. Are the surface fuels adequate to carry a fire across a shrubland community or woodland?
    b. If wooded, in what woodland phase (I, II, or III) is the stand? In addition to increasing fuel loads, later woodland phases, Phase II and especially Phase III, require more extreme weather conditions (lower humidity, higher temperatures and wind speeds) to carry fire due to lack of horizontal fuel continuity resulting from limited surface fuels.
    c If wooded, are the ladder fuels (primarily shrubs) sufficient to carry the fire into the tree canopy?

d. If wooded, are the fuels from the trees (tree sizes, distances between canopies, and canopy density phases) so great as to result in a high severity fire?

e. What type of weather conditions are necessary to carry a fire and what kind of fire will likely occur—low, moderate, or high severity?

f. How will site characteristics such as aspect and slope effect fire severity?

g. How do fuels influence the season (early, mid, or late summer or fall) of burning and when is it most appropriate (see Miller and others 2013 for effects of season of burning)?

Assessing prescribed fire severity

2. Was the severity of the prescribed fire low, medium, high, or mixed across the treatment area?

   a. What percentage of aboveground organic matter was consumed including trees, shrubs, herbs, and litter (see Appendix 5)?

   b. What is the size and distribution of unburned, low to moderately burned, and high severity burned patches across the treatment area?

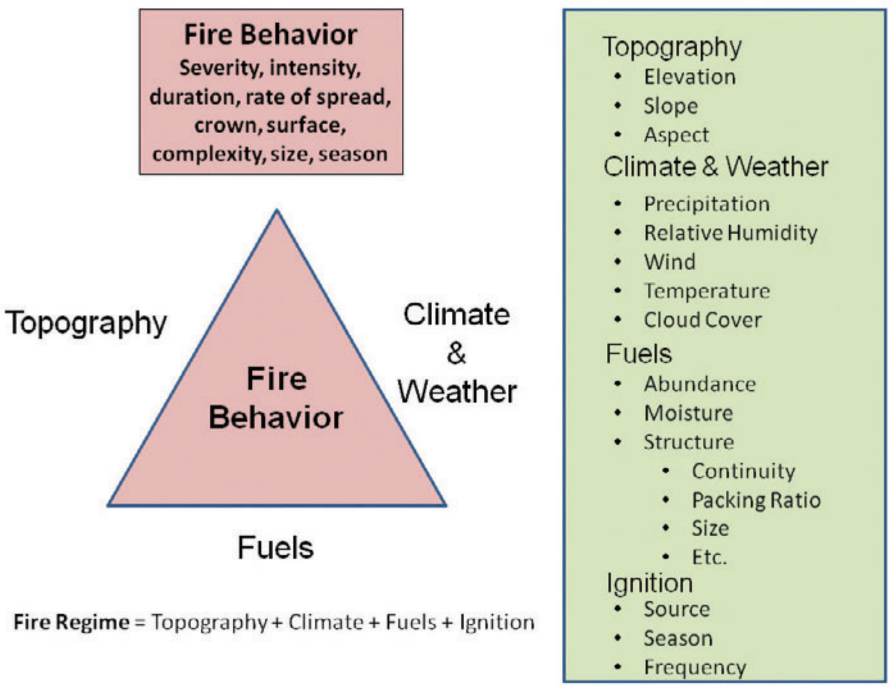


Figure 10. Fire behavior, including, intensity, duration, rate of spread, etc. are determined by three components: topography, climate and weather, and fuels. The specific traits of each of these components influence fire behavior and are closely related to fire severity.

Mechanical Treatment

Severity

Surface disturbance by mechanical treatments varies with the method used and season, and can range from minimal to moderate (for example, cutting and falling trees, cabling sagebrush, mulching trees with a brush hog) to severe (for example, chaining piñon pine and/or juniper, bulldozing, plowing). When evaluating mechanical disturbance, one should consider the proportion of area impacted, and the effects of the treatment on soil/site stability and hydrologic function as described in "Interpreting Indicators of Rangeland Health." Mechanical treatments that affect soil stability and hydrologic function are degree of soil movement (both depth and area), compaction, and the level of mortality of native species that results in a reduction in plant cover. Compaction can reduce infiltration rates (water capture) and seedling establishment. Soil movement that exposes bare soil or perennial plant roots can cause plant mortality and provides ideal seedbeds for invasive species.

5-Pre- and Post-Treatment Weather

Pre-treatment weather effects can be hard to quantify and post-treatment weather is unpredictable. However, weather conditions prior to a treatment can influence the abundance and continuity of fine fuel loads, percent dead fuels, and seed banks. Post-fire weather conditions can influence seedling establishment, recovery of plants that survive the treatment (both native and invasive species), and future seed crops. Consequently, weather can influence the type of post-treatment management actions including length of deferment from grazing or closure of treatment areas to off-road vehicles.

1. How has the weather 1-2 years prior to treatment affected the abundance and continuity of fine fuel loads?
2. How have potential seed banks (native and invasive species) been influenced by pre-treatment weather?
3. How will post-treatment weather influence successional pathways and will additional actions or multiple interventions potentially be needed (for example, invasive species control, seeding of native species, or transplanting sagebrush)?
   a. Seed banks of perennial native species are often low, and seedling establishment usually only occurs during wet springs, especially on warm-dry ecological sites.
   c. Favorable weather conditions can increase establishment, productivity, and seed-crops of both desirable and undesirable plant species.

    d. Recovery in the first 1-2 years is typically dependent on persistent perennial vegetation that survived the treatment.

4. What is the potential for wind or water erosion in the first 1-2 years post treatment?

6-Post-Treatment Management

1. Assuming proper livestock grazing management, how long should the treatment area be deferred from grazing? This deferment period may vary by ecological site and if so, the ecological site that is most sensitive to grazing impacts should dictate the deferment period. In addition, pre-treatment plant composition and structure, and treatment severity and timing, can influence length of the deferment period.
    a. Deferring grazing during the active growth period for the first two years is probably adequate only for ecological sites where:
        - Treatment severity will be low to moderate;
        - Resilience and resistance to invasives is high;
        - Pre-treatment herbaceous vegetation is dominated by natives and invasive annual grasses are only a minor component; and
        - Post-treatment monitoring indicates adequate recovery of shrubs, perennial grasses, and forbs.
    b. Deferring grazing during the active growth period for the first two years is probably inadequate where any of the following apply:
        - Treatment severity will likely be high;
        - Resilience to treatment and resistance to invasives are moderate to low;
        - Invasive annual grasses are co-dominant or dominant; and
        - Post-treatment monitoring indicates low or slow recovery of perennial grasses and forbs.

The amount of time for post-treatment grazing deferment necessary for recovery is largely determined by: treatment severity + ecological site characteristics + pre-treatment plant composition and structure + post-treatment weather.

2. What is the post-treatment level of control of grazing in terms of duration, stocking rates, distribution, and season of use?
3. What are the potential impacts of recreational use, wild horses and burros, and wildlife (for example, elk use in treated areas with increased grass abundance)?

The lack of adequate deferment or proper long-term grazing management can have a dramatic effect on the resilience and resistance of the treatment area (fig. 11)

Figure 11. Seven year post-fire response comparison for a cool mesic/aridic-xeric Wyoming big sagebrush/Thurber's needlegrass community in Nevada. Elevation is 7500-7800 ft and the area was grazed prior to treatment. The fence was installed after the fire. (**A**) In the absence of grazing perennial grasses have recovered and non-native invasive abundance is low. (**B**) Inappropriate grazing resulted in loss and/or limited recovery of deep-rooted perennial grasses and the dominance of non-native invasives.

7-Monitoring and Adaptive Management

A monitoring plan should be in place before the treatment is implemented.

1. Do the monitoring protocols measure the project objectives?
2. Are the monitoring methods consistent with those being used elsewhere?
3. Is a plan in place for data entry and analyses that is consistent across the agency(s) (for example, Land Treatment Digital Library; http://greatbasin.wr.usgs.gov/ltdl/)?
4. Is there a mechanism for summarizing the results and incorporating the relevant information into the planning process?
5. Is there a mechanism to share monitoring results with others implementing similar treatments on similar sites? The Joint Fire Science Program's Great Basin Fire Science Delivery Project can assist with this effort (www.gbfiresci.org).

Monitoring provides essential information on treatment outcomes that can be used to adjust future prescriptions and to determine if post-treatment actions are needed.

Selecting the Most Appropriate Treatment Method

State and Transition Models

State and transition models (STMs) can be used to illustrate potential successional pathways that result from both disturbance and restoration for different ecological sites. Appendix 6 provides STMs that represent five generalized ecological types occupied by big sagebrush for the Great Basin and Columbia River Plateau. For many areas, specific ecological site descriptions (ESDs) and STMs are available. See: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/ecoscience/desc/.

Identification and current condition of the specific or generalized big sagebrush ecological sites located on the proposed treatment area will help to determine which treatments are most appropriate and if treatments are likely to have desired outcomes (Appendix 7). Ecological site descriptions provide information on or related to (1) resilience, (2) resistance to invasive annuals species, (3) potential successional pathways following treatment, and (4) potential treatment requirements (burning, mechanical treatments, and/or seeding) and outcomes (shifts between phases and states).

Land Unit Evaluation Score Sheet

Appendix 8 provides a score sheet that can be used to help evaluate the level of ecological site resilience and resistance to invasive annual grasses and to determine the type of treatment and the likelihood of success or failure. Each major ecological site (or groups of similar ecological sites) within the proposed treatment area is evaluated with a separate score sheet. Scores are not absolute and should be used only as guidelines. The score sheet values can be modified when quantitative data and/or scientific studies provide better information or when the results of monitoring of similar treatments become available for the same ecological sites.

1. Mechanical treatments with minimal surface disturbance should be considered when:
    a. Resilience and resistant scores are <15 but sufficient perennial herbaceous species occur to promote recovery.
    b. It is desirable to retain the shrub layer.
    c. Species of concern will be more impacted by fire than mechanical treatment due to low fire tolerance or change in vegetation structure and composition.
2. Prescribed fire can be considered when:
    a. Resilience and resistance scores are >20; these are typically cool-moist ecological sites occupied by mountain big sagebrush.
    b. Large areas need to be treated.
    c. Funds are limited.
3. Plant successional pathways on areas being considered for treatment with scores between 15 and 20 are more difficult to predict.
    a. If the area being evaluated is cool aridic (10 to 12-in ppt) or cool xeric (>12-in ppt), then either low to moderate severity prescribed fires or mechanical treatments can be considered when sufficient perennial herbaceous species exist to promote recovery.
    b. If the area being evaluated is dry aridic (<10-in ppt), the use of fire should be discouraged.
    c. If the area is aridic (10-12-in ppt) and perennial herbaceous vegetation is depleted, the use of fire should be discouraged unless reseeding follows immediately after the fire and the soil moisture + temperature score is >10.

    Note that if the area is a priority area for conservation of sage grouse but sagebrush cover is a limiting factor at the landscape scale, reseeding or transplanting sagebrush should be considered if prescribed fire is used.
4. When predicted successional pathways will not meet the objectives of increasing or restoring resilience to disturbance and resistance to annual invasive grasses following treatment, a logical decision is “not to treat.” Exceptions include:
    a. Critical habitat where sufficient funds exist for repeated interventions, and/or integrated strategies can be used such as fire treatments followed by control of invasive annual grasses and revegetation.
    b. Urban-wildland interface areas where fuels treatments are needed to decrease fire risk.
    c. Critical portions of a watershed where treatment is necessary to prevent erosion or the introduction of an invasive seed-source.

General Rule—the warmer and drier the proposed treatment area, the greater the risk of invasive annual grasses and the more important the residual vegetation is for recovery.

Advantages and Disadvantages of Prescribed Fire

The majority of native perennial grasses and forbs are fire tolerant. However, mortality can vary widely ranging from <10% to >90% depending upon the amount of time that herbaceous plant crowns are exposed to lethal temperatures. Fire intensity (heat released) and duration are influenced by weather conditions, fuels, composition and packing of live and dead fuels in grass crowns, and topography (fig. 10) (for additional information on fire effects on individual plant species see Fire Effects Information System; http://www.fs.fed.us/database/feis/).

Advantages—Fire is a natural process and vegetation can respond positively given careful selection of the area to be treated. It is often the most economical treatment and large areas can be treated. When used to reduce tree encroachment, fire usually results in a longer time interval before retreatment is required resulting from the removal of small trees that often survive mechanical treatment. Fire severity can be controlled somewhat by the prescription, which includes pre-fire fuel treatments and weather conditions at the time of the fire.

Disadvantages—Fire often results in a greater risk of invasive annual species dominance in low to mid elevation sites (mesic and dry-aridic soils). Fire typically results in increased resource availability (for example, nitrogen) in the first 1-3 years after burning compared to mechanical treatments that have minimal to moderate soil disturbance. This flush of nutrients can decrease resistance to invasive annuals on sites with favorable climatic conditions. Fire also reduces or eliminates shrubs, especially those that are fire intolerant. Recovery of Wyoming big sagebrush following fire in warm-dry ecological sites (mesic/aridic), especially in dry-aridic (<10-in), is very slow to nearly non-existent (Miller and others 2013). However, recovery of mountain big sagebrush on cool-moist ecological sites typically occurs within 25-35 years. Fire also results in a significant reduction in soil biological crusts that typically contribute a major portion of plant cover on mesic/aridic soils and minimize the amount of cheatgrass in a plant community. Prescribed fire can include potential liability issues and concerns such as smoke, wildlife, and the urban interface. Also, successful prescribed fire requires adequate fuels and climate conditions, and additional costs can be incurred when a prescribed fire is postponed due to extreme or limiting weather conditions, and/or air quality concerns.

Advantages and Disadvantages of Mechanical Treatments

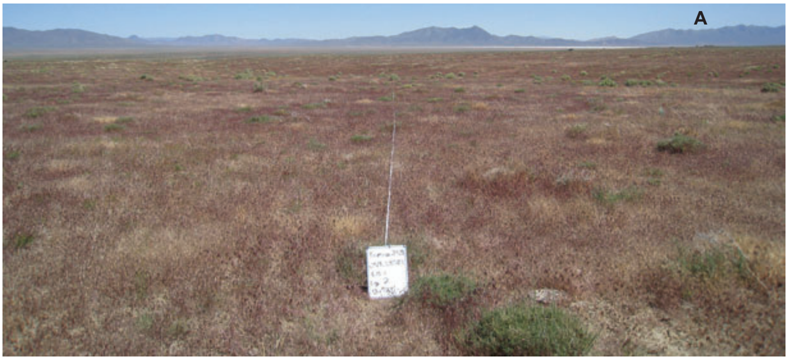
Advantages–Mechanical treatments can maintain a desired level of the shrub component and, where applicable, be selective in which trees are targeted. Some methods cause minimal soil disturbances such as when cut-and-leave treatments are used or tire impact from heavy equipment is minimized. The boundaries of the area treated are easily controlled and there is a broad time period when treatments can be applied. Liability is minimal and mechanical treatments can be successfully used near the wildland urban interface. Light surface disturbance also can enhance the seedbed for seedling establishment and have minimal impacts on cover of soil biological crusts.

Disadvantages–Mechanical treatments can leave large amounts of woody debris following treatment of Phase II to Phase III woodlands and can result in high soil disturbance (compaction or soil surface movement) under certain conditions. Mechanical treatments typically have a high cost/acre, take longer to treat large areas than prescribed fires, and some equipment is limited by steepness and roughness of the terrain. Clearance costs on federal lands also may be higher per acre compared to prescribed fire, especially for archeological surveys if increased surface disturbance is expected. Mechanical treatments such as mowing to establish a fuel break can result in an increase in fine fuels if the understory has a significant cheatgrass component.

Seeding Considerations

The decision to seed should be based on (1) ecological site characteristics that strongly contribute to degree of success (see fig. 3, seeding success increases with resilience), and (2) current composition and structure of native and invasive species.

Ecological Site Characteristics–Seeding success on ecological sites with severely depleted perennial grasses and forbs varies across ecological sites. Native seeding success on severely depleted ecological sites with warm-mesic to mesic and dry aridic (<10-in precipitation) soil temperature/moisture regimes is extremely low (accumulative soil moisture and temperature score ≤10) (fig. 12). Using introduced wheatgrasses can slightly improve seeding success on these sites but may not meet management objectives. Seeding success on cool-mesic/aridic ecological site (10-12-in precipitation) is usually mixed, and is highly dependent on annual moisture in the first 2-3 years following treatment (score = 12-15) (fig. 13). Seeding success on frigid/xeric ecological sites (score = 14-17) is typically high. Environmental factors such as precipitation timing and



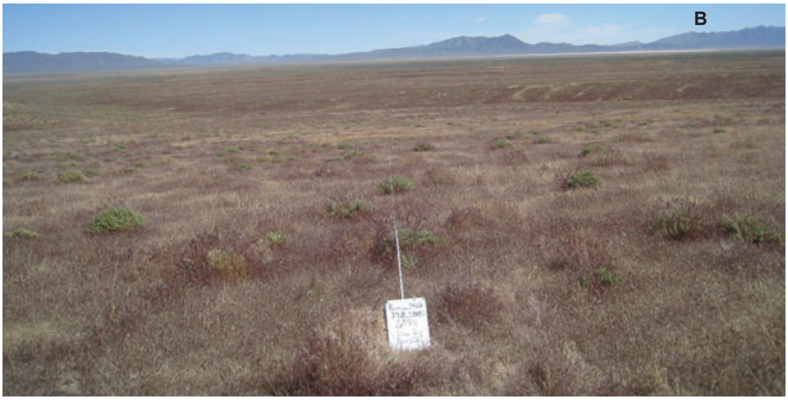


Figure 12. Nine-year post wildfire (2002) response for adjacent (A) seeded and (B) unseeded communities. Ecological site is a warm-mesic/dry-aridic Wyoming big sagebrush/Indian ricegrass-Sandberg bluegrass, elevation 5000 ft southeast of Gerlach Nevada. Native herbaceous vegetation prior to the burn was likely severely depleted to absent and the presence of a sagebrush canopy was unknown. Soil moisture + temperature score = 9, total score 9-12. This site has low suitability for seeding and low resilience to disturbance. The treated site (A) was drill seeded to native grasses in the fall following the fire and (B) was not seeded. Cover in the treated site (A) is 0% native deep-rooted perennial grasses, 61% cheatgrass, 3.3% native shrub cover and 6% non-native shrub cover. Cover in the untreated site (B) is 0% deep rooted perennial grasses, 89% cheatgrass, 6.7% native shrub cover and 0% non-native shrub cover.

amount, which cannot be controlled nor predicted, can affect seeding success even on cool mesic/aridic and frigid/xeric ecological sites.

Need and Effect—Potential treatment areas where perennial herbaceous species are absent or severely depleted will need to be seeded post-treatment if the ecological site characteristics are suitable for success (cumulative soil moisture and temperature usually scores $\geq$12). However, for areas with scores >10-15 that have sufficient perennial herbaceous species to recover following a prescribed fire or mechanical treatments, seeding with introduced species or aggressive cultivars will likely retard or prevent recovery of the native community.

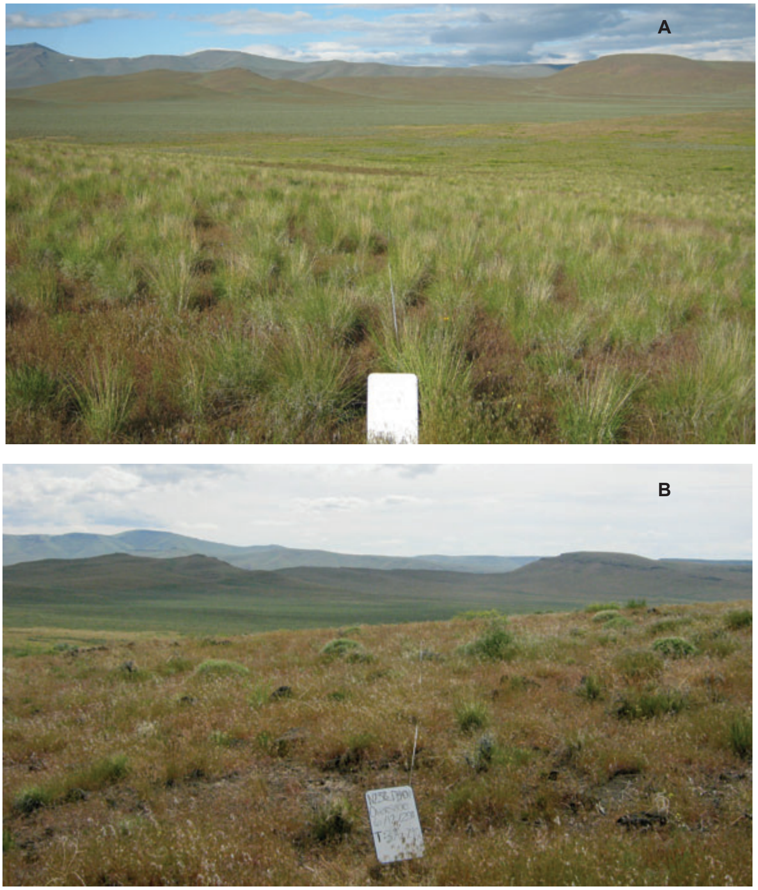


Figure 13. Nine year post wildfire (2002) response for adjacent (A) seeded and (B) unseeded communities. Ecological site is a cool-mesic/aridic Wyoming big sagebrush/bluebunch (10-12-in PZ) south of Rome Oregon, elevation 5000 ft. Native herbaceous vegetation prior to the burn was likely severely depleted to absent and the presence of a sagebrush canopy unknown. Soil moisture + temperature score = 12; total score 12-15. Treated (A) was drill seeded to native grasses in the fall following the fire and (B) was not seeded. Cover in the treated site (A) is 23% native deep-rooted perennial cover and 65% cheatgrass, and in the untreated site (B) is 7% native deep-rooted perennial cover and 69% cheatgrass.

Selecting Treatment Areas

What, where, and how much to treat is usually determined by priorities, potential outcomes, needs, available resources, and funding availability. Questions to address when selecting areas to be treated include:

1. What are the chances of success based on the areas resilience to disturbance and resistance to invasive species, which are closely linked to ecological site characteristics and plant community composition and structure at the time of treatment?
2. Does the area provide important habitat for animal and/or plant species of concern?
3. Can treatment increase the landscape connectivity for species of concern?
4. Is the proposed treatment area a major source of sediment to nearby streams or does it have high erosion potential?
5. What is the treatment cost?
6. Is retreatment likely to be needed and, if so, is it an option?
7. Can post-treatment management be modified to promote attainment of project objectives? For example, can livestock grazing be deferred long-enough for the site to recover, and can appropriate grazing be implemented to maintain the treatment objectives once the decision to graze has been made?

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Appendix 1. Primary components and characteristics (from figures 1 and 3) that influence resilience to disturbance, resistance to invasive annual grasses, and successional trajectories.

Component	Attributes
Ecological site (figs.1, 3 and 4)	Regional location (MLRA) Climate Topography • Elevation, aspect, slope, landform and landscape position (consider how topography effects water movement & storage, & heat loads) Soils • Soil moisture and temperature regimes • Depth, texture, % organic matter, structure (consider factors that influence water storage and availability) Potential vegetation within the reference state • Species composition and structure (e.g., biomass, cover, density, etc.) • Potential production in favorable, average and unfavorable years

Current vegetation	Vegetation productivity (annual production)
	Species composition and structure relative to the ecological site description
	• Fire tolerant & non-tolerant species (morphology)
	• Native & invasive species
	  • Residual perennial herbaceous species are often more important for recovery than seed banks and seed sources
	• Potential for invasive species
	  • Environmental characteristics of the site (e.g., mesic to warm frigid; s-facing slopes
	  • Relative abundance of perennial herbaceous species
	  • On site and adjacent invasive seed banks and potential seed rain
	Fuel load and structure
	  • Woodland phase (fire severity increases with increased tree biomass)
	  • Fine surface fuels and structure (biomass, continuity, packing ratios)
	Woodland age structure (pre- and post-settlement tree densities)
	Amount and distribution of bare ground (gap size between perennial plants)Amount and distribution of biological soil crusts
	At-risk-phase?

Disturbance history (figs. 1 and 3; pre- and post)	Severity and frequency Time since last event Type • Fire • Mechanical • Drought • Herbivory, including livestock, native and introduced herbivores • Disease, snow-mold, fungus, etc. • Insects
Fire severity (fig. 10)	Fuels Topography Fire weather Season (linked with fire weather and plant phenology) Current vegetation (fuel abundance and structure) Fire type • Ground, surface, crown, head fire, backfire and backing fire

Pre-treatment weather (previous 1-3 years)	Timing and amount of precipitation
	Temperatures (primarily extremes) Consider how it has influenced
	  • Fuels
	  • Seed banks
	  • Pre-treatment species composition

Appendix 2: Soil temperature and moisture regimes and general ranges in elevation for indicator plant species in the Great Basin and Columbia River Plateau regions. Examples are shown for the Malheur High Plateau (MLRA23) and Central Nevada Basin and Range (MLRA 28B). Considerable variability exists within an MLRA so multiple indicators should be used.

Soil temperature regime		Elevation (ft)[a]		PPT (in)	Moisture regime	Indicator plants[b]	Ecological zones
		MLRA 23	MLRA 28B				
Mesic	Warm	<3000	4000-6000	4-8	Typic Aridic	Arsp, Atco, Krla, Heco, Achy	Desert basins
	Cool	3000-4000	5500-6500	8-12	Aridic bordering Xeric	Arno, Artrw, (few Juos or Juoc), Acth	Sagebrush semi-desert
Frigid	Warm	4000-5000	6000-8000	12-14	Xeric bordering Aridic	Arno, Arar, Artrv, Artrw, Juos or Juoc, Acth	Upland sagebrush, juniper
	Cool	5000-6000	7500-8200	14+	Typic Xeric	Artrv, Symph, Amal, Pimo, Feid, Acne, snow pocket Potr	Upland mountain sagebrush
Cryic	Warm	6000-7500 (8000)	8200-9600	16+	Typic Xeric	Artrv, Arsp, Arar, Symph, Amal,Cele, Abco, Potr	Mountain brush
	Cool	8000-9000	9300-10,600	18+	Typic Xeric	Pien, Piar, Pifl	High mountain
	Cold	>9000	10,600-13,061	20+	Xeric bordering Aridic	Alpine plants	Subalpine and alpine

[a] Elevation is usually adjusted 500 ft for north (-) or south (+) aspects, and elevation breaks change from north to the south ends of the MLRA. Elevation and indicator species should be fine-tuned for a specific management area. It is also important to consider that changes along elevation gradients or from north to south locations within an MLRA are usually gradual and are not defined by distinct boundaries.

[b] Plant codes: Abco=*Abies concolor*, Achy=*Achnatherum hymenoides*, Acne=*Acnatherum nevadense*, Acth=*Achnatherum thurberianum*, Amal=*Amelachier alnifolia*, Arar=*Artemisia arbuscula*, Arno=*Artemisia nova*, Arsp=*Artemisia spinescens*, Artrv=*Artemisia tridentata* spp. *vaseyana*, Artrw=*Artemisia tridenatata* spp. *wyomingensis*, Atco=*Atriplex confertifolia*, Cele=*Cercocarpus ledifolius*, Feid=*Festuca idahoensis*, Heco=*Hesperostipa comata*, Juoc=*Juniperus occidentalis*, Juos=*Juniperus osteosperma*, Krla=*Krascheninnikovia lanata*, Piar= *Pinus aristata*, Pifl=*Pinus flexilis*, Pimo=*Pinus monophylla*, Symph=*Symphoricarpos* sp., Potr=*Populus tremuloides*.

Appendix 3. What is the meaning of a soil family name?

Soil Family Names

In general, soil family names ending in "olls" are Mollisols indicating that they have a minimum of 1% organic matter. Soils ending in "ids" are Aridisols. They contain <1% organic matter, usually occur in aridic precipitation zones, and are less productive than Mollisols. Both soil orders are common in the Great Basin. Examples of naming protocols for Mollisols and Aridisols follow.

1 **Course sandy loam mixed mesic aridic Typic Haploxerolls**

2 **Clayey smectic frigid lithic xeric Haplargids**

3 **Fine loamy mixed super active xeric Argicryolls**

4 **Loamy skeletal mixed frigid Pachic Haploxerolls**

Soil texture / temperature / moisture

Soil 1: Warm (mesic) dry (aridic) soil with an aridic moisture regime that is approaching xeric (xer for xeric) or 12 inches precipitation (PPT). This soil has the lowest potential resilience to disturbance and resistance to invasives due to its' mesic-aridic soil temperature-moisture regime.

Soil 2: A cool (frigid), moist (xeric), shallow (lithic) soil with an accumulation of clay in the B horizon (argi for argillic layer) and ≥12 in PPT. This soil has the lowest potential infiltration rates due to the presence of an argillic layer and the lowest storage potential due to a shallow soil depth (lithic = shallow) and <1% organic matter content.

Soil 3: A cold (cry for cryic), moist (xeric, ≥12 in PPT) soil with an accumulation of clay in the B horizon (argi). This soil has the highest potential resistance to invasive species due to the cold temperature regime. Potential resilience will usually decline along a gradient from warm-cryic to cold-cryic as a result of a shortened growing season.

Soil 4: A moist (xer), cool (frigid), rocky (skeletal) soil. This soil has relatively high resilience and moderate resistant to invasives. It has the highest water capture potential of the four soils due to the loamy soil texture and lack of an argillic layer.

Soil Terms

Arigillic—typically defined by percent increase in alluvial clay content (usually the B horizon) relative to the overlying soil layer (usually the A horizon). The increase in clay and abrupt change in texture can substantially reduce infiltration rates.

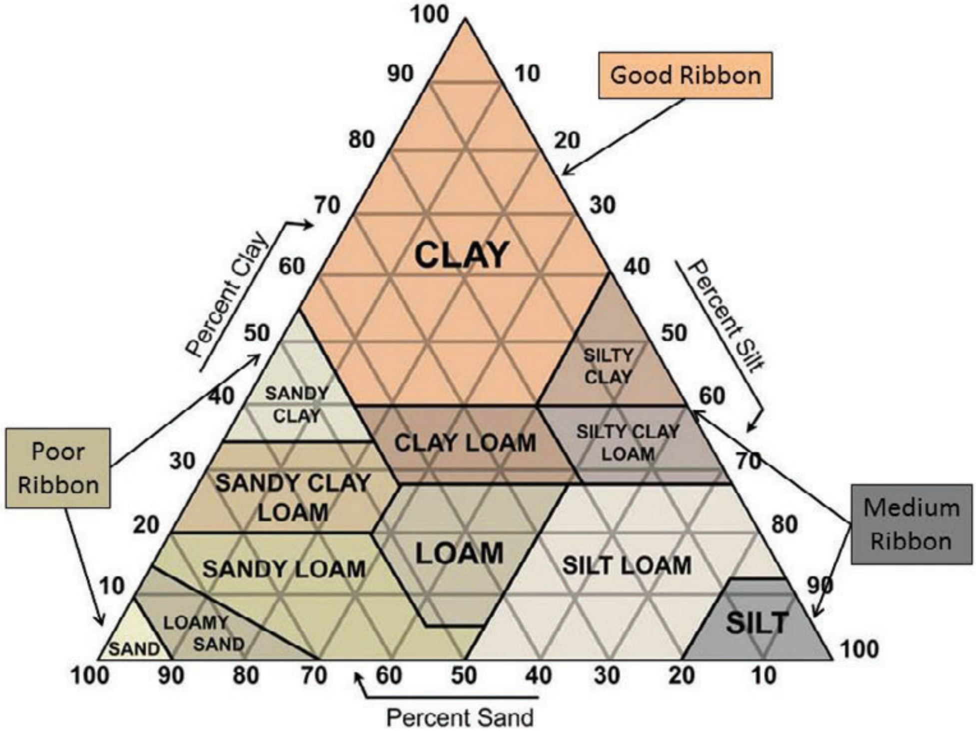
Duripan—a subsurface horizon that is cemented by alluvial (water transported) silica to the degree that fragments from the air-dry horizon do not slake (take in water or crumble) during prolonged soaking.

Lithic—shallow soils over a paralithic (soft bedrock) contact or duripan (subsurface horizon cemented by bedrock).

Skeletal—soils with ≥35% particle sizes >2 mm by volume.

Soil depth—very shallow <10 in; shallow 10-20 in; moderately deep 20-36 in; deep >36 in.

Soil moisture regime—an important soil property that, in combination with growing season soil temperature, influences plant growth and biological soil processes. The moisture regime is based on the amount of soil moisture available during the growing season in areas with moist-cool winters and hot-dry summers. Although mapped as distinct breaks in precipitation (<12 in or >12 in), soil moisture regimes are continuous gradients changing with location and elevation. Thus, it is important to consider where the site fits along the gradient. For example, a site with an aridic moisture



regime that receives 11.5 in of precipitation will often be more resilient to disturbance than an aridic site receiving 9 in of precipitation. For a detailed definition and description for each soil moisture regime see USDA-NRCS 1999. For this field guide, we define the following soil moisture regimes:

a. **Dry-Aridic** <10 in

b. **Aridic—**10-12 in **Xeric –** 12-14 in

c. **Moist xeric—**>14 in

Soil temperature regime—an important property of a soil that, along with soil moisture, influences plant growth and biological soil processes. Soil temperature is usually measured at 50 cm depth (20 inches) (or depth at the lithic or paralithic contact), which is considered deep enough to reflect seasonal temperatures and not daily cycles. Since measurements of seasonal soil temperatures are spatially limited across the Great Basin, soil temperature regimes are estimated based on seasonal air temperatures, which are largely influenced by location, elevation, and aspect. When soils are mapped, temperature regimes are most commonly based on elevation and aspect, which are adjusted for each sub-region (MLRA). For a detailed definition and description for each soil regime, see USDA-NRCS 1999.

a. **Mesic** (warm)**—**indicator species are Wyoming big sagebrush and black sagebrush. Mesic soils have low relative resistance to invasives compared to frigid and cryic soils. They also are considered to have lower resilience.

b. **Frigid** (cool)**—**indicator species are mountain big sagebrush, piñon pine, and low sagebrush on shallow soil, but black sagebrush and occasionally Wyoming big sagebrush may occur on the warmer end of this soil regime or where soil moisture is limiting. Resilience to disturbance and resistance to invasive species are higher than on mesic soils.

c. **Cryic** (cold)**—**cryic soils are cooler in summer than frigid soils. Indicator species are curleaf mountain mahogany, white and grand fir, limber pine, lodgepole and white bark pine, which typically intermingle with mountain big and low sagebrush. Resilience is high on the warm end of this regime, but declines as temperatures become colder due to limitations on plant growth. Resistance to invasive species is higher than for mesic and likely frigid soils (although data are limited).

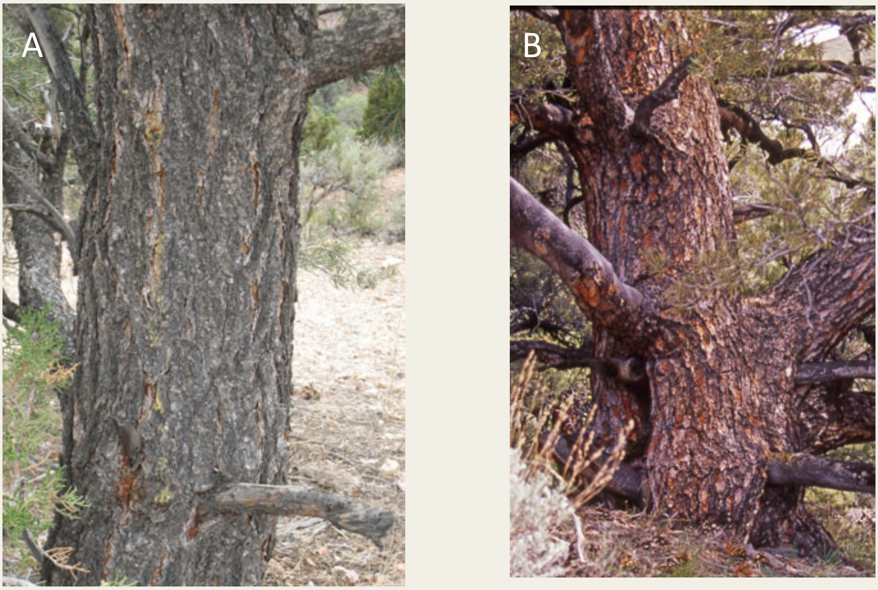
Appendix 4a: Characteristics that differentiate post and pre-settlement woodlands. There are several types of woodlands based on stand age in the Great Basin and Columbia River Plateau region. These include: (1) old-growth woodland; (2) woodland that was formerly old growth, but that is currently occupied by young trees (< 150 years old) as a result of a stand replacing disturbance; (3) tree shrub savanna where the old trees are less than 10% canopy cover; (4) tree shrub savanna that is infilled by post-settlement young trees; and (5) sagebrush shrub-steppe occupied by young trees.

Woodland Characteristics and Tree Growth Form

Characteristic	Post-Settlement Trees	Pre-Settlement Trees
Juniper crown shape	Conical with point tip	Flattened, rounded, or uneven tops
Piñon crown shape	Conical with pointed to slightly rounded tip	Flattened, rounded, or uneven top
Juniper branch structure	Branches get progressively smaller from bottom to top of tree	In open stands, large branches near the base
Piñon branch structure	Branches become smaller from bottom to top of tree, general orientation is vertical	In open stands branches large near base and remain relatively large well into the crown, more randomly oriented
Juniper bark	Flaky, relatively thin with limited or shallow vertical furrows	Thick, fibrous with well-developed vertical furrows
Piñon bark	Relatively thin, flaky, with weak vertical furrows	Thicker, more plate-like structure than furrowed
Juniper leader growth	Terminal leader growth in the upper 1/4 of the tree usually >2 in. In open stands, leader growth >2 in from bottom to top	Leader growth in the upper 1/4 of the tree usually <1 in
Piñon leader growth	Leader growth in piñon similar to juniper but not directly visible. Must look for bud scale scares to determine length	Leader growth in upper 1/4 of the tree usually <2 in.
Tree canopy lichen	Little or no foliose lichen on juniper	Juniper often covered by bright green foliose lichen
Dead wood in standing tree	Little dead wood in bole, few to no dead trees, logs, or large stumps	Dead branches, bark missing, black stain and/or black lichen
Large wood across the site	Large diameter logs and stumps absent	Large diameter logs and stumps, often charred, scattered across the site

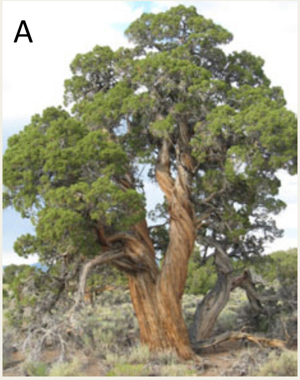
Appendix 4b. Photos showing examples and comparisons between old and young trees.

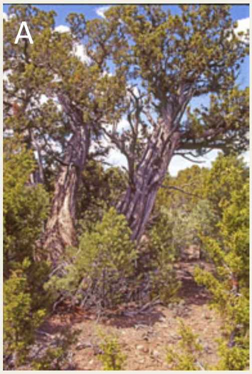
4b. Bark on western and Utah juniper is typically flaky and thin on trees <130-150 years. Bark on trees around 150-180 years is thicker and beginning to develop vertical furrows. On trees >200 years furrows continue to develop and the bark becomes very fibrous (usually around >250 years). (Photos of Utah juniper by Robin Tausch)



(A) Bark on singleneedle piñon pine is relatively thin and flaky, and weak vertical furrows occur on trees <130 years. (B) Trees >300 years have thicker bark that is more plate-like than furrowed. (Photos by Robin Tausch).

These old western (A) and Utah (B) junipers have multiple old-growth characteristics including yellow-green foliose lichen (on the western juniper), black lichen and black stain (often mistaken for charred wood), dead wood including part of the trunk, and very limited leader growth at the branch tips. The bark is deeply furrowed and very fibrous.





Both Utah (A) and western (B) juniper exhibit flattened or rounded crowns sometimes with dead tops, twisted trunks, very limited terminal and lateral growth on the branch tips, and bark that is thick, furrowed and fibrous. Singleneedle pinyon pine (C) exhibits dead branches, thick platy bark, and a flattened round crown. (Photos A and C by Robin Tausch)

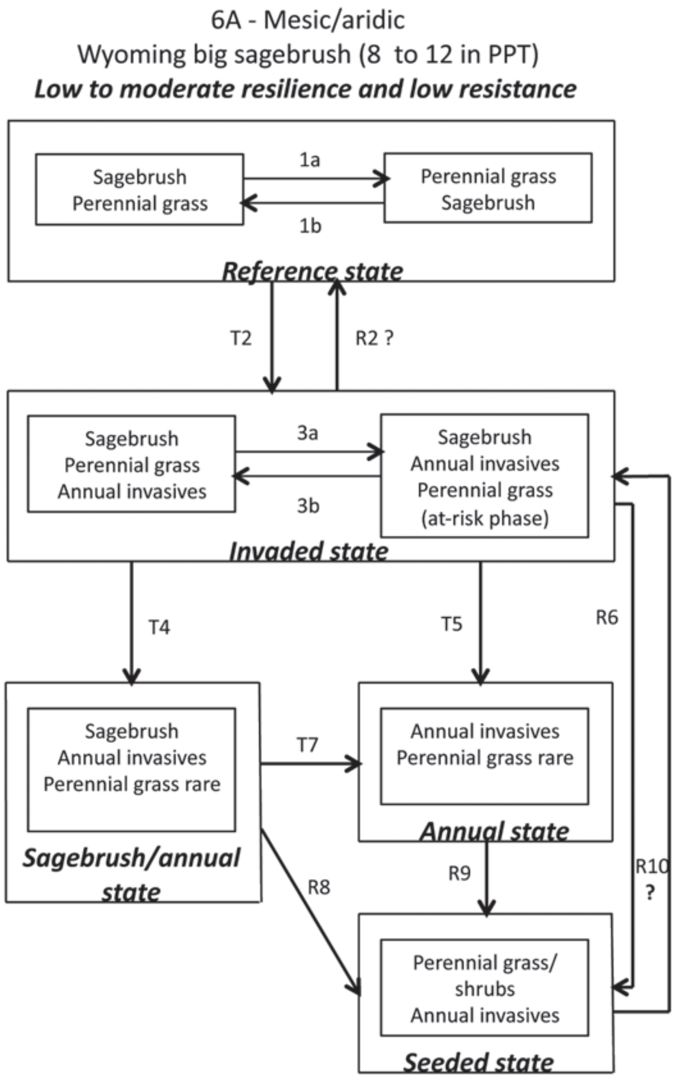
Low density of old trees killed by fire that would have formed a savannah with understories of (A) mountain big sagebrush-bitterbrush/Idaho fescue and (B) Wyoming big sagebrush/needlegrass. Both communities have more than a 10-fold increase in young trees compared to pre-burn densities. Size and density of snags, stumps, and logs can help project stand structure prior to the fire. (A) Fire occurred around 1900. (B) Time since fire in unknown. (Photo B by Robin Tausch)

Appendix 5. Post-burn indicators of fire severity. Soil and litter indicators are derived from Parson and others (2010).

Low severity	Moderate severity	High severity
>75% burned sagebrush skeletons remaining	15-75% burned sagebrush skeletons remaining	Sagebrush basal stumps remain or burned below the soil surface
<25% tree foliage dead, <15% foliage consumption	25-75% tree foliage dead, 15-50% foliage consumed	>75% tree foliage dead, >50% consumed
Tree duff blackened but little consumed	Majority of tree duff consumed surface blackened	White ash layer beneath tree canopy
>2 in blackened stubble remains on burned grasses	0.25-1in blackened stubble remains on burned grasses	Grass crowns consumed to or below the surface
Unburned patches >50%	Unburned patches 15-50%	Unburned patches <15%
Interspace litter consumption <50%	Interspace litter consumption 50-80%	Interspace litter consumption >80%, white ash deposition
Shrub canopy litter consumption < 50%	Shrub canopy litter consumption 50-80%	Shrub canopy litter consumption >80%, white ash deposition
No ash, ground fuels blackened & recognizable	Thin layer of black to gray ash, some litter recognizable	Layer of powdery gray or white ash >90% surface organics consumed
No fire induced water repellency	Weak to medium water repellency at or just below the surface	Strong water repellency at or below the surface
Surface soil structure unchanged	Surface structure slightly to not altered	Aggregated stability reduced or destroyed, surface loose and/or powdery

Appendix 6. State-and-transition models (STMs) for five generalized ecological types for big sagebrush.

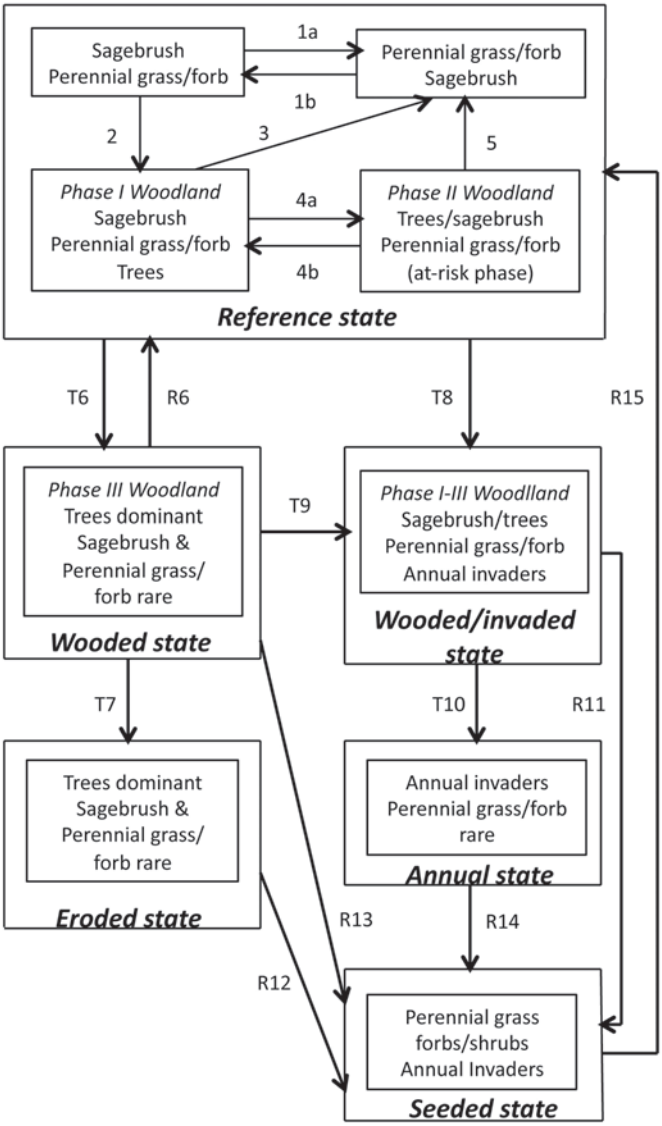
These STMs represent groupings of ecological types that are occupied by Wyoming or mountain big sagebrush, span a range of soil moisture-temperature regimes (warm-dry to cold-moist), and characterize a large portion of the Great Basin and Columbia River Plateau regions: (A) Mesic/aridic Wyoming big sagebrush in an 8-12-in precipitation zone (PZ); (B) Cool mesic to warm frigid/xeric frigid mountain big sagebrush in a 12-14-in PZ; (C) Cryic/xeric mountain big sagebrush/mountain brush in a 14+ in PZ; (D) Cool mesic to warm frigid/xeric mesic big sagebrush with piñon pine and juniper potential in a 12-14-in PZ, and (E) Cool frigid/xeric mountain big sagebrush with piñon and juniper potential in a 12-14+ in PZ. Large boxes illustrate states that are comprised of community phases (smaller boxes). Transitions among states are shown with arrows starting with T; restoration pathways are shown with arrows starting with R. The "at risk" community phase is most vulnerable to transition to an alternative state.



(1a) Perennial grass increases due to disturbances that decrease sagebrush like wildfire, insects, disease, and pathogens.
(1b) Sagebrush increases with time .
(T2) An invasive seed source and/or improper grazing trigger an invaded state.
(R2) Proper grazing, fire, herbicides and/or mechanical treatments are unlikely to result in return to the reference state on all but the coolest and wettest sites.
(3a) Perennial grass decreases and both sagebrush and invasives increase with improper grazing resulting in an at-risk phase. Decreases in sagebrush due to insects, disease or pathogens can further increase invasives.
(3b) Proper grazing and herbicides or mechanical treatments that reduce sagebrush may restore perennial grass and decrease invaders on wetter sites (10-12”). Outcomes are less certain on drier sites (8-10”) and/or low abundance of perennial grass.
(T4) Improper grazing triggers a largely irreversible threshold to a sagebrush/ annual state.
(T 5 and T7) Fire or other disturbances that remove sagebrush result in an annual state. Perennial grass is rare and recovery potential is low due to low precipitation, mesic soil temperatures, and competition from annual invasives. Repeated fire can cause further degradation.
(R6, R8 and R9) Seeding following fire and/or invasive species control results in a seeded state. Sagebrush may recolonize depending on patch size, but annual invasives are still present.
(R10) Seeding effectiveness and return to the invaded state are related to site conditions, seeding mix, and post-treatment weather.

6B - Cool mesic to warm frigid/xeric
Big sagebrush (12-14 in PPT)
Piñon pine and/or juniper potential

Moderate resilience and moderately low resistance



(1a) Disturbances such as wildfire, insects, disease, and pathogens result in less sagebrush and more perennial grass/forb.

(1b) Sagebrush increases with time .

(2) Time combined with seed sources for piñon and/or juniper trigger a Phase I Woodland.

(3 and 5) Fire and or fire surrogates (herbicides and/or mechanical treatments) that remove trees may restore perennial grass/forb and sagebrush dominance on cooler/wetter sites. On warmer/drier sites with low perennial grass/forb abundance resistance to invasion is moderately low.

(4a) Increasing tree abundance results in a Phase II woodland with depleted perennial grass/forb and shrubs and an at-risk phase.

(4b) Fire surrogates (herbicides and/or mechanical treatments) that remove trees may restore sagebrush and perennial grass/forb dominance .

(T6) Infilling of trees and improper grazing can result in a biotic threshold crossing to a wooded state with increased risk of high severity crown fires.

(R6) Fire, herbicides and/or mechanical treatments that remove trees may restore perennial grass/forb and sagebrush dominance on cooler/wetter sites.

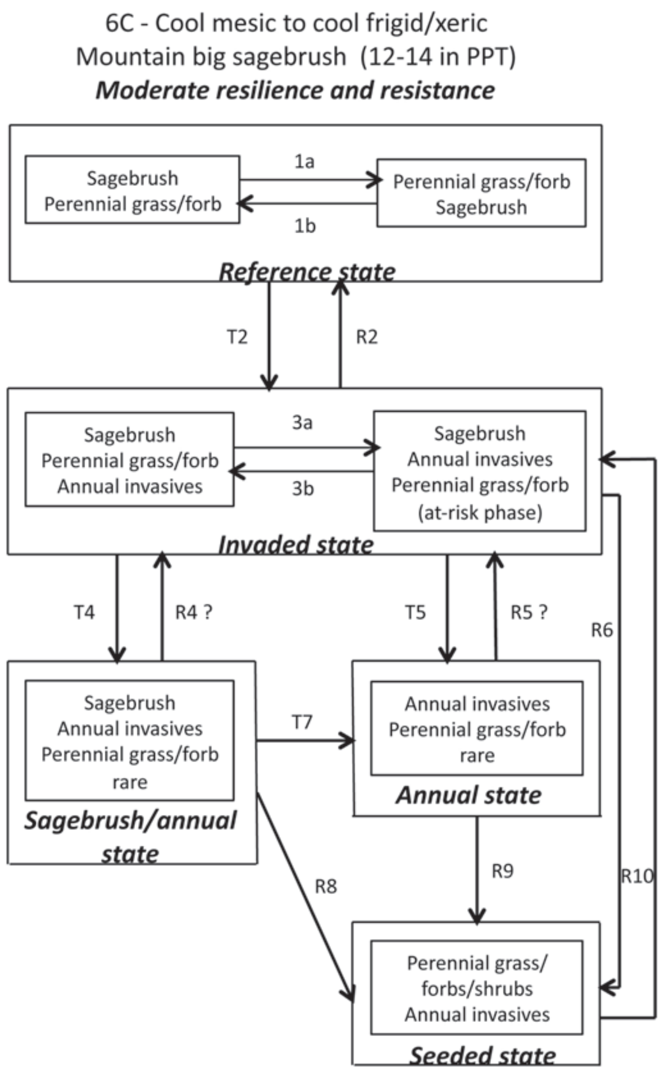
(T7) An irreversible abiotic threshold crossing to an eroded state can occur depending on soils, slope, and understory species.

(T8 and T9) An invasive seed source and/or improper grazing can trigger a wooded/invaded state.

(T10) Fire or other disturbances that remove trees and sagebrush can result in a biotic threshold crossing to annual dominance on warmer/drier sites with low resilience.

(R11, R12, R13, and R14) Seeding after fire and/or invasive species control increases perennial grass/forb. Sagebrush may recolonize depending on seed sources, but annual invaders are still present. Seeded eroded states may have lower productivity.

(R15) Depending on seed mix , grazing, and level of erosion, return to the reference state may occur on cooler and wetter sites if an irreversible threshold has not been crossed.



(1a) Perennial grass/forb increases due to disturbances that decrease sagebrush like wildfire, insects, disease, and pathogens.

(1b) Sagebrush increases with time .

(T2) An invasive seed source and/or improper grazing trigger an invaded state.

(R2) Proper grazing, fire, herbicides, and/ or mechanical treatments may restore perennial grass/forb and sagebrush dominance with few invasives.

(3a) Perennial grass/forb decreases and sagebrush and invasives increase with improper grazing by livestock resulting in an at-risk phase. Decreases in sagebrush due to insects, disease or pathogens can further increase invasives.

(3b) Proper grazing, herbicides, or mechanical treatments that reduce sagebrush may increase perennial grass/ forb and decrease invasives.

(T4) Improper grazing results in a sagebrush/annual state.

(R4) Proper grazing may facilitate return to the invaded state on cooler/wetter sites if sufficient grass/forb remains .

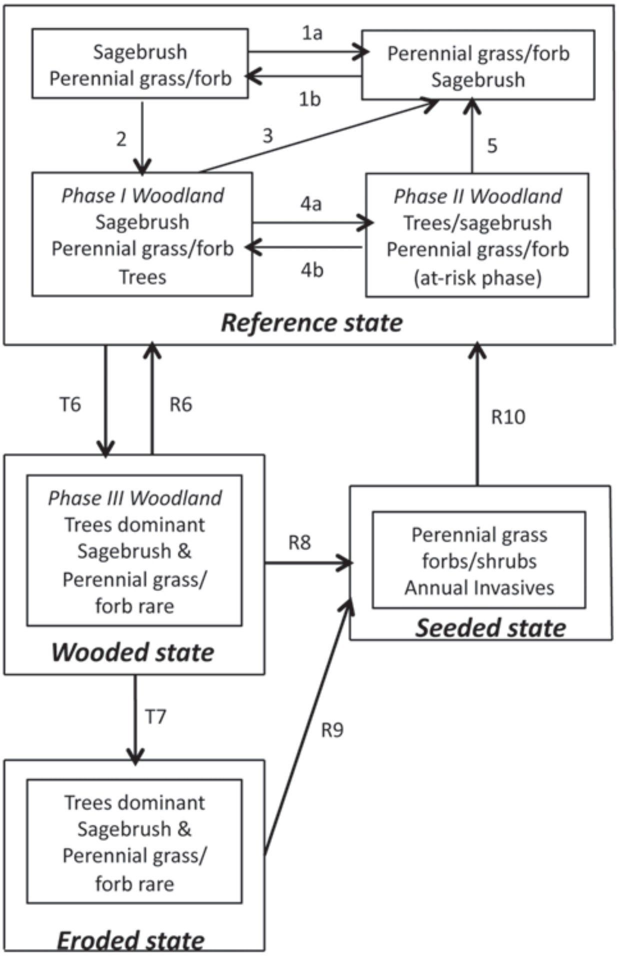
(T5 and T7) Fire or other disturbances that remove sagebrush result in an annual state. Perennial grass/forb are rare and recovery potential is reduced. Repeated fire can result in a biotic threshold crossing to annual dominance on warmer/drier sites, and root-sprouting shrubs may increase.

(R5) Cooler and wetter sites may return to the invaded or reference state with lack of fire, proper grazing, and favorable weather.

(R6, R8 and R9) Seeding following fire and/or invasive species control results in a seeded state. Sagebrush may recolonize depending on patch size, but annual invaders are still present.

(R10) Cooler and wetter sites may return to the invaded or possibly reference state depending on seeding mix, grazing and weather.

6D - Cool frigid/xeric
Mountain big sagebrush (12 -14 in + PPT)
Piñon pine and/or juniper potential
Moderately high resilience and resistance



(1a) Disturbances such as wildfire, insects, disease, and pathogens result in less sagebrush and more perennial grass/forb.

(1b) Sagebrush increases with time .

(2) Time combined with seed sources for piñon and/or juniper trigger a Phase I Woodland.

(3 and 5) Fire and or fire surrogates (herbicides and/or mechanical treatments) that remove trees may restore perennial grass/forb and sagebrush dominance.

(4a) Increasing tree abundance results in a Phase II woodland with depleted perennial grass/forb and shrubs and an at-risk phase.

(4b) Fire surrogates (herbicides and/or mechanical treatments) that remove trees may restore perennial grass/forb and sagebrush dominance.

(T6) Infilling of trees and/or improper grazing can result in a biotic threshold crossing to a wooded state with increased risk of high severity crown fires .

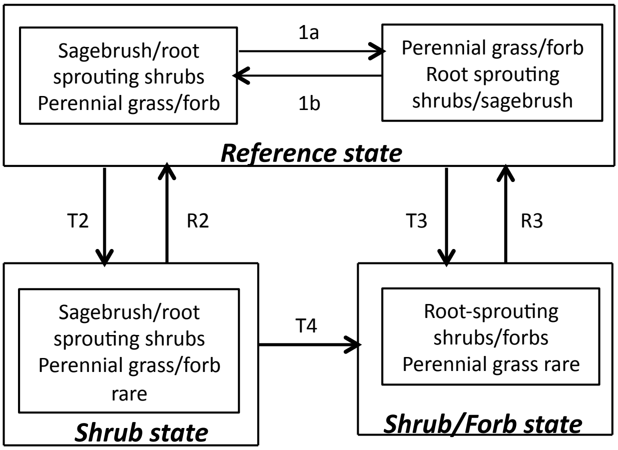
(R6) Fire, herbicides and/or mechanical treatments that remove trees may restore perennial grass/forb and sagebrush dominance.

(T7) An irreversible abiotic threshold crossing to an eroded state can occur depending on soils, slope, and understory species.

(R8 and R9) Seeding after fire may be required on sites with depleted perennial grass/forb, but seeding with aggressive introduced species can decrease native perennial grass/forb. Annual invasives are typically rare. Seeded eroded states may have lower productivity.

(R10) Depending on seed mix and grazing, return to the reference state may be possible if an irreversible threshold has not been crossed.

6E - Cryic/xeric mountain big sagebrush/
Mountain brush (14 in + PPT)
Moderately high resilience and high resistance



(1a) Perennial grass/forb increases due to disturbances that decrease sagebrush like wildfire, insects, disease, and pathogens.

(1b) Sagebrush and other shrubs increase with time.

(T2) Improper grazing triggers a shrub dominated state.

(R2) Proper grazing results in a return to the reference state.

(T3 and T4) Fire or other disturbances that remove sagebrush result in dominance by root-sprouting shrubs and an increase in native forbs like lupines.

(R3) Proper grazing and time result in return to the reference state.

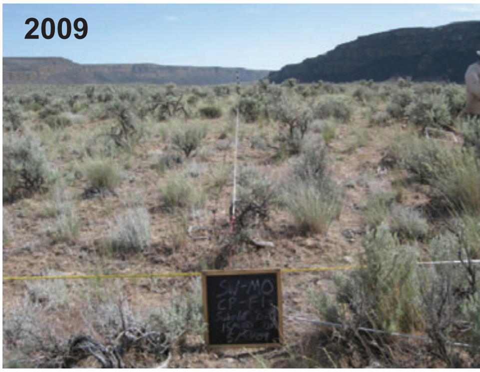
Note: Resilience is lower on cold cryic sites due to short growing seasons.

Appendix 7. Examples of states, phases, and transitions following prescribed fire or mechanical treatment for three general ecological types in different phases (photos from SageSTEP plots; PZ = precipitation zone). For interpretation of resilience scores see Appendix 9.

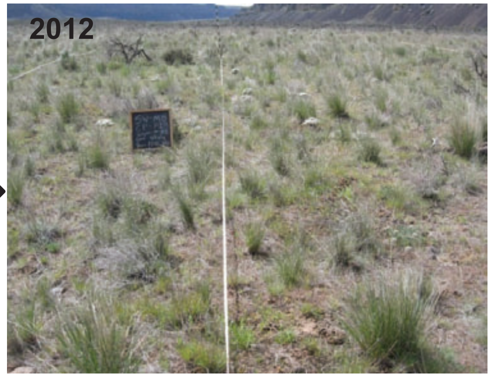
7A—Warm-mesic/aridic

Wyoming big sagebrush/bluebunch wheatgrass-Sandberg bluegrass (8-12-in PZ)

Reference State



Fire

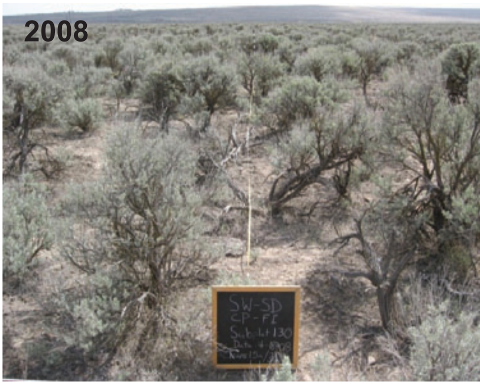


Fire resistant bluebunch wheatgrass is abundant, Sandberg bluegrass fills the interspaces, and cheatgrass is only a trace. Although warm-mesic aridic, the area has a high probability for a successful outcome with fire or mechanical treatment. Resilience score = 20

7B—Warm-mesic/aridic

Wyoming big sagebrush/bluebunch wheatgrass-Indian ricegrass (8-12-in PZ)

Invaded State



Fire

Severely depleted and cheatgrass cover near 5%. Following a prescribed fire invasive annuals dominate the understory. Resilience and resistance to invasive annuals and potential seeding success is low. Resilience score = 9

7C—Cool mesic/aridic

Basin & Wyoming big sagebrush/bluebunch wheatgrass (10-12-in PZ)

Juniper potential

Reference State
Phase I woodland/sagebrush/perennial grass/
forb

Fire

Mechanical

Near reference state: bluebunch wheatgrass is abundant and cheatgrass only a trace. The area has a high probability for a successful outcome with fire or mechanical. Resilience score = 20

Eroded State
Phase III woodland
Shrubs & perennial herbs rare

Mechanical

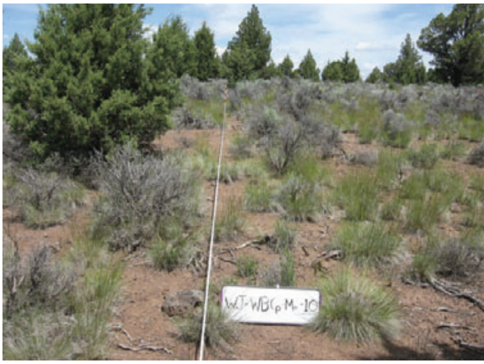
Recovery of this site is questionable. Native herbs present but severely depleted and cheatgrass seed source present. Post-treatment management will be critical. Resilience score = 14

7D—Cool frigid/xeric

Mountain big sagebrush/Idaho fescue (12-14-in PZ)

Juniper potential

Reference State



Fire →

The presence of Idaho fescue indicates this is a cool-frigid soil temperature regime. The herbaceous layer is dominated by native grasses and forbs. There is only a trace of invasive annuals. Nearly 100% sagebrush mortality was caused by Aroga moth prior to the prescribed fire. The combination of good herbaceous plant composition + soil moisture/temperature regimes results in high resilience and resistance. Fire or mechanical control can be used on this site, particularly since the sagebrush cover is gone. However, the lack of ladder fuels will make it difficult to kill the trees with fire. On this site, some mechanical preparation was required to carry the fire into the tree canopies. Resilience score = 25.

Appendix 8a.

Evaluation sheet for ecological sites within the proposed treatment area to evaluate resilience after disturbance and resistance to invasives if the treatment is implemented based on soil temperature and moisture indicators and current plant composition. Evaluation scores based on soil moisture and temperature indicators can be used to determine site suitability for seeding following treatment.

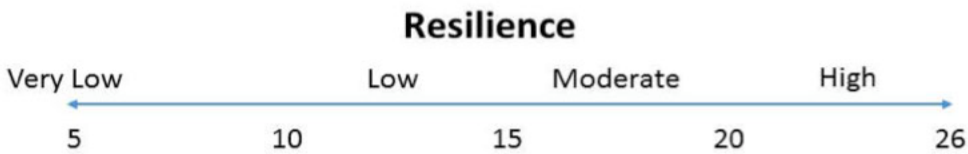
Score sheet for resilience to management treatment and resistance to annual invasives						
Very low = < 10, Low = 10 to < 15, Moderate = 15-20, High = 20						
Ecological site name ______________________		**Stand (plot)[a]**				
Site characteristics	Variable	1	2	3	4	5
% of Area	estimated					
Temperature						
Soil temperature regime	mesic = 1, frigid = 2, cryic = 3					
At the warm or cool end of the regime	warm = 1 (if warm cryic = 3), mid = 2, cool = 3 (if cool cryic = 1)					
Subspecies of sagebrush	Wyoming, low, and black = 1, Basin = 2, Mt = 3					
***Total Temperature**						
Moisture						
Precipitation	< 10-in = 1, 10-12-in = 2, 12-14-in = 3, >14-in = 4					
Soil texture	Clay = 1, sandy = 1, silty = 1, silty, sandy or clay loams = 2, loam = 3					
Soil depth1	very shallow = 0 (<10-in), shallow = 1 (10-20-in), moderately deep = 3 (20-36-in)					
***Total moisture**						
Total Moisture + Temperature	If score is <10 seeding is extremely risky					
Current vegetation (CV): Native perennial grasses (PG) and forbs (PF)	weighted score x 3					
Scarce to severely depleted; <2-3/m^2 = **0**	0					
PG depleted; <3 per m^2 and/or codominant with BRTE = **2**	6					
PG & PF dominant = **3**	9					
Trt severity (TS)						
% = survival of perennial herbaceous vegetation	Low severity prescribed fire or mechanical treatment = CV x 95%					
	Moderate severity prescribed fire or mechanical treatment = CV x 80%					
	High severity prescribed fire = CV x 20%					
***Adjusted CV = CV x TS**						
Total resilience score	*Total temp + *Total moisture + *Adjusted CV = resilience score					

[a] The stand or plot should be uniform in topography and soils, and fit within one ecological site.

Appendix 8b. Definitions for Land Unit Evaluation Sheet.

Resilience (potential recovery) score sheet				
Very low = <10, Low 10-<15, Moderate 15-20, High = 20				
		Score		
Site characteristics	**Variable**	**min**	**max**	**Definition**
% of treatment area within an ecological site	estimated			Percentage of area proposed to be treated composed of a particular ecological site is estimated.
Temperature				
Soil temp regime	mesic = 1, frigid = 2, cryic = 3	1	3	Based on guidelines for each MLRA (see Appendix 2)
Is the site at the warm or cool end of the regime?	warm = 1, mid = 2, cool = 3 (warm cryic = 3, cool cryic = 1)	1	3	Refer to Appendix 2 to adjust for elevation. Elevation is usually adjusted for aspect. For example in MLRA23, frigid = 4000-6000 ft + 500 ft for north (-) or south (+).
Subspecies of sagebrush	Wyoming, low, and black = 1, Basin = 2, Mt = 3	1	3	Wyoming Big Sagebrush, Black Sagebrush, and Low Sagebrush = 1; Basin big sagebrush = 2; Mountain big sagebrush = 3
Moisture				
Precipitation	<10-in = 1, 10-12-in = 2, 12-14-in = 3, >14-in = 4	1	4	
Soil texture	Clay = 1, sandy = 1, silty = 1, silty, sandy or clay loams = 2, loam = 3	1	3	Loams have good infiltration rates and water storage capacity for plant growth.
Soil depth1	very shallow = 0 (<10-in), shallow = 1 (10-20-in), mo in	0	3	Soil depth is one of the major variables in determining water storage capacity and rooting depth.
Current vegetation (CV)	weighted score x 3			Score is weighted so importance is equal to moisture regime plus temperature regimes.
Perennial grasses and forbs				Perennial species that would be expected to be dominant to co-dominant within the reference state.
Absent to severely depleted = 0	0	0	0	PG < 2/m^2 for xeric and < 3/m^2 for aridic; invasives dominant or, if invasives are not dominant, woody species (shrubs or trees) are near maximum cover.
Depleted or codominant with BRTE = 2	6	6	6	Abundance of PG and PF are near or equal to abundance of invasives (annual exotic abundance is highly variable with moisture). If invasives have low abundance (< 5% cover), PG >2/m^2 for xeric and > 3/m^2 for aridic.
Dominant = 3	9	9	9	Native herbaceous species are dominant on the site.
Trt severity				
% = survival of perennial herbaceous vegetation	Low severity prescribed fire or mechanical treatment = CV x 95%	0	8.1	Mechanical treatments that have a high degree of disturbance on the soil surface can have moderate severity.
	Moderate severity prescribed fire or mechanical treatment = CV x 80%			Phase I and II woodlands and high density shrublands can burn at moderate severity depending on prescription.
	High severity fire = CV x 20%			Phase III woodlands usually burn at high severity.
Total min and max		5	27.1	

Appendix 8c. Example: Wyoming big sagebrush/Thurber needlegrass community (Appendix 6—mesic/aridic Wyoming big sagebrush (8-12-in PPT State and Transition model in variable condition and burned in a wild fire of varying severity.



Resilience ratings based on score sheet.

Example: Potential vegetation on this ecological site is Wyoming big sagebrush and Thurber needlegrass. Soil temperatures vary from warm mesic to cool mesic depending on elevation and aspect. Mean annual precipitation is 10-12 in. Soils are moderately deep clay loams. Current vegetation ranges from severely depleted on approximately 65% of the area and native perennial grasses and forbs dominating the understory on 15% of the area. Fire severity varied from low to moderate. Resilience on the majority of the area (75%) is very low to low. The only area where resilience is moderate to approaching high is where native perennial herbaceous vegetation is dominant.

Score sheet for resilience to disturbance and resistance to annual invasives							
Very low = < 10, Low = 10 to < 15, Moderate = 15-20, High = 20							
Ecological site name ______________________		**Stand (plot)[a]**					
Site characteristics	**Variable**		**1**	**2**	**3**	**4**	**5**
% of Area	estimated		40	10	25	10	15
Temperature							
Soil temperature regime	mesic = 1, frigid = 2, cryic = 3		1	1	1	1	1
At the warm or cool end of the regime	warm = 1 (if warm cryic = 3), mid =2, cool=3 (if cool cryic = 1)		1	2	1	2	2
Subspecies of sagebrush	Wyoming, low, and black = 1, Basin = 2, Mt = 3		1	1	1	1	1
***Total Temperature**							
Moisture							
Precipitation	< 10-in = 1, 10-12-in = 2, 12-14-in = 3, >14-in = 4		2	2	2	2	2
Soil texture	Clay = 1, sandy = 1, silty = 1, silty, sandy or clay loams = 2, loam = 3		2	2	2	2	2
Soil depth[1]	very shallow = 0 (<10-in), shallow = 1 (10-20-in), moderately deep = 3 (20-36-in)		3	3	3	3	3
***Total moisture**							
Total Moisture + Temperature	If <10 seeding extremely risky		**10**	**11**	**10**	**11**	**11**
Current vegetation (CV): Native perennial grasses (PG) and forbs (PF)	weighted score x 3						
Scarce to severely depleted; <2-3/m^2 = **0**	0	0		0			
PG depleted; <3 per m^2 and/or codominant with BRTE = **2**	6			6		6	
PG and PF dominant = **3**	9						9
Trt severity (TS)							
% = survival of perennial herbaceous vegetation	**Low severity** prescribed fire or mechanical treatment = CV x 95%			X			X
	Moderate severity prescribed fire or mechanical treatment = CV x 85%		X			X	
	High severity fire = CV x 20%				X		
***Adjusted CV = CV x TS**							
Total Resilience Score	*Total Temp + *Total Moisture + *Adjusted CV = resilience score		**6**	**15.3**	**2.2**	**13.6**	**18**

[a]The stand or plot should be uniform in topography and soils, and fit within one ecological site.

Appendix 9. Definitions of terms used in this field guide. For soil terms see Appendix 4.

At-risk phase—a community phase that is most vulnerable to transition to an alternative state (for example, least resilient). See definition of phase below.

Ecological site—An ecological site (ES) is a conceptual division of the landscape that is defined as a distinctive kind of land based on recurring soil, landform, geological, and climate characteristics that differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its ability to respond similarly to management actions and natural disturbances; similar to ecological type used by USDA Forest Service and the old term used by the NRCS.

Ecological site descriptions (ESD)—The documentation of the characteristics of an ecological site. The documentation includes the data used to define the distinctive properties and characteristics of the ecological site; the biotic and abiotic characteristics that differentiate the site (i.e., climate, physiographic, soil characteristics, plant communities); and the ecological dynamics of the site that describe how changes in disturbance processes and management can affect the site. An ESD also provides interpretations about the land uses and ecosystem services that a particular ecological site can support and management alternatives for achieving land management; similar to the ecological type used by USDA Forest Service and the old term used by the NRCS, Range Site Description.

Ecological type—a category of land with a distinctive (i.e., mappable) combination of landscape elements: climate, geology, geomorphology, soils, and potential natural vegetation. Ecological types differ from each other in their ability to produce vegetation and respond to management and natural disturbances.

Major Land Resource Areas/MLRAs—geographic area, usually several thousand acres in extent, that is characterized by a particular pattern of soils, climate, water resources, land uses, and type of farming.

Phase (community)—community phases interact with the environment to produce a characteristic composition of plant species, functional and structural groups, soil functions, and range of variability. Phases may not progress directly to the most resilient community phase without passing through an intermediate phase.

Potential vegetation—potential vegetation of an ecological site, as described in an ESD, is a function of ecological site characteristics (climate, topography, and soils), attributes and processes (soil moisture-temperature regime, soil processes, and vegetation dynamics), and disturbance history

Reference state—historic or potential plant community including seral (successional) stages; based on conditions believed to be present before widespread alterations by Euro-Americans.

Resilience—capacity of an ecosystem to regain its fundamental structure, processes and functioning when altered by stresses like increased CO_2 , nitrogen deposition, and drought and to disturbances like land development and fire.

Resistance—capacity of an ecosystem to retain its fundamental structure, processes and functioning (or remain largely unchanged) despite stresses, disturbances or invasive species.

Resistance to invasion—abiotic and biotic attributes and ecological processes of an ecosystem that limit the population growth of an invading species.

Restoration pathways—restoration pathways describe the environmental conditions and management practices that are required to recover a state that has undergone a transition.

State—a suite of plant community successional phases ocurring on similar soils that interact with the environment to produce resistant functional and structural attributes with a characteristic range of variability that are maintained through autogenic repair mechanisms.

Treatment area—an area that is being considered for some form of vegetation manipulation (prescribed fire or mechanical treatments) to increase resilience and/or resistance or that has experienced a wildfire. The treatment area is often composed of different ecological sites that may have different resilience to disturbance and resistance to invasives (a result of varying elevation, topography, soils, and disturbance history). It is helpful to place these sites into general groups based on soil moisture/temperature regime and current vegetation.

Woodland phase I, II, III—phase I: trees are present but shrubs and herbs are the dominant vegetation influencing ecological processes on the site; phase II: trees are codominant with shrubs and herbs and all three vegetation layers influence ecological processes; phase III: trees are the dominant vegetation on the site and the primary plant layer influencing ecological processes on the site (from Miller and others 2005). Phases can be calculated using % cover (from Roundy and others 2014).

Phase I = total tree / total tree + shrub + perennial grass = < 0.33 (tree biomass <1/3)

Phase II = total tree / total tree + shrub + perennial grass = 0.34-0.65 (tree biomass 1/3 to 2/3)

Phase III = total tree / total tree + shrub + perennial grass = > 0.66 (tree biomass > 2/3)

Phases of woodland succession

Characteristics (post-settlement stands)	**Phase I (early)**	**Phase II (mid)**	**Phase III (late)**
Tree canopy % of maximum potential cover	Open, actively expanding <1/3 max potential	Open, actively expanding 1/3 to 2/3 max potential	Expansion nearly stabilized >2/3 max potential
Leader growth dominant trees, cm/yr	Terminal > 10 lateral > 10	Terminal >10 lateral 5 to >10	Terminal >10 lateral <5
Crown lift* dominant trees	Absent	Absent	Lower limbs dying or dead where tree canopy >40%
Tree recruitment	Active	Active	Limited to absent
Potential berry production	Low	Moderate to high	Low to near absent
Leader growth (understory trees, cm/yr)	Terminal >10 lateral >8	Terminal 5 to >10 lateral 2 to >8	Terminal <5 lateral <2

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